

# micro paleontology

volume 4

number 1

january 1958

PUBLISHED BY:

Department of Micropaleontology  
American Museum of Natural History  
Central Park West at Seventy-Ninth Street  
New York 24, New York

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The subscription price of this quarterly is \$8.00 per year. Single copies are \$2.50 each.



# **micropaleontology**

**volume 4**

**Department of Micropaleontology  
American Museum of Natural History  
New York**

**1958**

*DATES OF ISSUE*

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*Number 1 - March 18, 1958*

*Number 2 - April 18, 1958*

*Number 3 - July 8, 1958*

*Number 4 - November 26, 1958*

**ABSTRACT:** *The value of smaller foraminifera in Upper Palaeozoic stratigraphy is enhanced greatly by the adoption of an integrated procedure of analysis, using assemblages from both the hard and the soft rocks of any one sequence. This partial fusion of the "solid" and thin-section analytical methods reveals the inadequacies of each when employed singly. Its combined character leads to much greater accuracy in palaeontological and stratigraphic studies, and, at the same time, indicates many of its own limitations. In the present paper, examples are drawn from the British Avonian Palaeotextulariidae to illustrate the combined method.*

## The faunal analysis and stratigraphic application of Upper Palaeozoic smaller foraminifera

ROBERT H. CUMMINGS

*University of Glasgow*

**EDITORS' NOTE:** *This is the third in the series of papers by Dr. Cummings on Upper Palaeozoic smaller foraminifera. His second paper, on the textulariids, appeared in Micropaleontology, volume 2, number 3, July, 1956.*

### INTRODUCTION

The present use of smaller foraminifera in Upper Palaeozoic stratigraphy involves one of two types of analysis, depending upon the nature of the host sediment. Many studies have been based on free solid specimens of microfossils extracted by various methods from the more friable marine sediments. Thus, in Brady's classic monograph (1876), most of the described forms were recovered from the soft calcareous shales of the British upper Visean. The extensive work of Cushman, Waters, Warthin, and others in the American Pennsylvanian was based largely on solid specimens, with sectional studies of test interiors sometimes included to further morphologic description. But the fullest stratigraphic application of such microfaunas requires both a detailed morphologic examination and a complete unraveling of their phylogenetic and palaeogeographic patterns by population analysis in all rock types. To rely solely on the faunas from friable rocks is to provide a very incomplete and often misleading assessment.

The other analytical method relies mainly on random thin sections in indurated rocks, from which the extraction of solid microfossils by maceration or disintegration is impossible. This practice is employed by many Soviet micropalaeontologists working in the Upper Palaeozoic, including Rauser-Chernous-

sova, Reitlinger, Vissarionova, and others. From an assessment of an assemblage of random thin sections, the concept of a morphospecies is established and described, and the random section showing the greatest number of biocharacters is cited as the type specimen. Each species thus identified is named and its complete stratigraphic range delineated. In many ways this technique is similar to that universally employed in the study of larger foraminifera, but there are several significant differences. The morphologic differentiation and systematic distinction of larger foraminifera are based almost entirely on differences in internal structure, but this is not the case in many of the groups of smaller foraminifera. The Palaeotextulariidae have a biocharacter of major systematic importance in the form and sequence of the apertural condition, which is not readily observed in sections. In the past, generic determinations of a single or a few random sections in limestone have often proved incorrect because of the inadequacy of morphologic detail (Cummings, 1956). There are, indeed, many inadequacies inherent in this type of analysis whose presence is not fully recognised, and whose effects must be minimised before the full stratigraphic value of the smaller foraminifera can be assessed.

Some Upper Palaeozoic sequences are composed entirely of indurated rocks and others wholly of friable sediments, but the great majority have these two conditions intimately intermingled, with one or the other predominating. In the classic British section of the Avon Gorge, the overall predominance



of indurated limestones is offset at many horizons by thin softer bands which yield solid microfossils after extensive treatment. This close interweaving of the two controlling conditions reflects not only the lithology but also primary depositional characteristics. It follows that a complete unraveling of the faunal sequence, which is also dependent on such characteristics, can be achieved only by a close interplay of the two types of analysis and by integrating their results.

Solid specimens reveal the complete document of morphology, specific variation, assemblage distribution, and controls in a friable rock horizon. They can be employed further to partially identify random thin sections of similar forms in adjacent, more indurated beds. Such a fusion of the two current methods of analysis widens the scope of faunistic control in stratigraphy. In addition, it reveals the limitations and inadequacies of employing one method without the other in any stratigraphic study.

The application of smaller foraminifera in the stratigraphy of the British Lower Carboniferous has been brought about by developing this integrated technique. In many ways it may appear to be a radically new method and to differ widely from the concepts of past and contemporary biostratigraphers. In essence, however, it attempts merely the revision and coordination of existing widely used techniques and an acknowledgment of the imperfections of the resultant. Since it may prove to be readily applicable throughout other Upper Palaeozoic areas, it is described in this work, the Palaeotextulariidae being used as a vehicle of illustration.

The author would like to acknowledge the encouragement and advice he has received throughout this work from Professor T. Neville George.

#### FAUNAL ANALYSIS

##### Identification of sections

Present terminology for the identification of planes of section in foraminifera is purely descriptive, and is confined largely to the oriented sections used in the determination of larger foraminifera. Glaessner

(1945) has modified the terminology suggested originally by Reichel (1936) for such oriented sections, and has pointed out the synonymous use of such terms as "median," "equatorial," "sagittal," and "horizontal." A review of recent foraminiferal literature shows considerable laxity, even in the definition of such important planes of section. The "median" of one author is frequently the same as the "transverse" of another.

Since a large proportion of most stratigraphic studies based on Upper Palaeozoic smaller foraminifera must rely on random thin sections in limestone, an initial stage in the development of the technique has been the introduction of a more concise method for defining the planes of section. This may be achieved by imposing on the solid form of the foraminifer, in an arbitrary and conventional manner, a system of three axes, A, B, and C, all at right angles to one another.

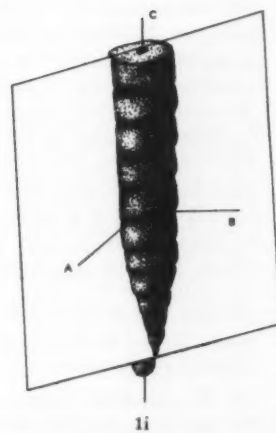
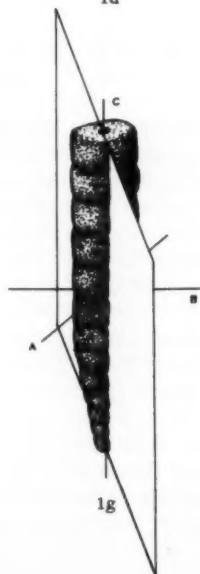
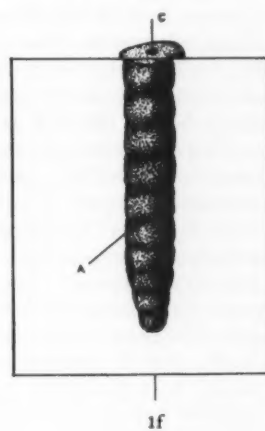
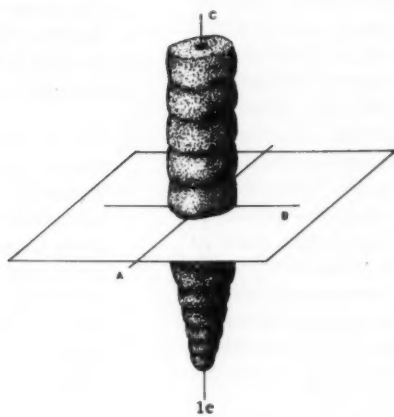
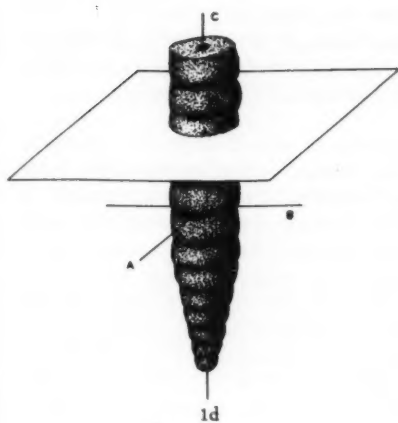
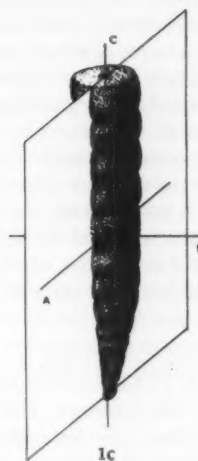
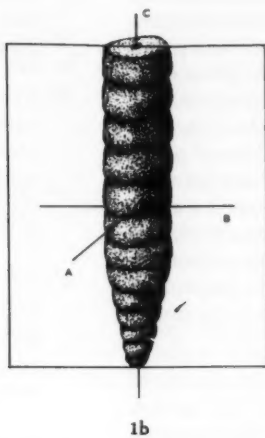
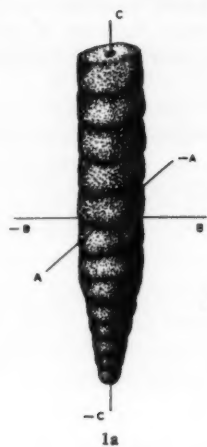
This system is illustrated in text-figure 1 with a solid specimen of the palaeotextulariid *Monogenerina*. Here the C-axis is defined as the straight line passing through the centres of the proloculum and the apertural face. Its midpoint within the specimen is identified as the origin through which the A- and B-axes are drawn at right angles to each other and to the C-axis. The axes are given positive and negative values on either side of the origin, as shown in text-figure 1a. Unit distance along each axis is measured from the origin to the points of emergence. Thus, the distance along the C-axis from the origin to the point where it emerges on the apertural face is defined as 1, and, in the opposite direction, to the point where it emerges from the base of the proloculum, as 1<sup>-</sup>; the positive sign is conventionally omitted except in one case described below, and the negative sign is shown following the value (viz., 1<sup>-</sup>).

Having identified the three axes in this arbitrary manner, it is then possible to define the attitude of any plane of section cutting the solid specimen of *Monogenerina* in a manner similar to the method of parameters widely employed in solid geometry and crystallography. This attitude may be expressed conventionally as three values, separated by diagonal

TEXT-FIGURE 1

*Monogenerina* sp., diagrams showing the positions of axes and representative planes of section, all approximately  $\times 50$ : a, arrangement of axes; b,  $0/\infty/\infty$ ; c,  $\infty/0/\infty$ ; d,  $\infty/\infty/1/2$ ; e,  $\infty/\infty/0$ ; f,  $1/2/\infty/\infty$ ; g,  $A+45^\circ B+/\infty$ ; h,  $\infty/1/2/3/4$ .

# ANALYSIS OF SMALLER FORAMINIFERA



strokes, and arranged in the order A / B / C. Thus, text-figures 1d and 1e both show the position of a transverse plane of section. In the case of text-figure 1e, this may be defined as  $\infty/\infty/0$ , since the plane of section lies parallel to and within the plane of A and B, and is cut by C at the origin. Similarly, the transverse section in text-figure 1d can be identified by the symbol  $\infty/\infty/\frac{1}{2}$ , for it lies parallel to the plane of A and B, and cuts C at a point midway between the origin and its point of emergence on the apertural face. The value of  $\frac{1}{2}$  is conventionally shown without the positive sign. Should the transverse section have cut C midway between the origin and its point of emergence at the base of the proloculum, it would have been designated  $\infty/\infty/\frac{1}{2}^-$ .

In like manner, the three longitudinal planes of section may be located in a more or less precise manner by this notation: that of text-figure 1b as  $0/\infty/\infty$ ; that of text-figure 1c as  $\infty/0/\infty$ ; and, by slight adaptation, that of text-figure 1g as  $A+45^\circ B^+/\infty$ . The latter is an example of the special type of notation employed when the plane of section lies along one of the axes and between the other two, cutting these two simultaneously at the origin. This condition is the sole exception to the standard representation based on A / B / C. The symbol  $A+45^\circ B^+$  may be interpreted as "the plane of section lies at an angle of  $45^\circ$  from the positive A-axis and toward the positive B-axis." In such cases the positive and negative values are always indicated, and representation is based on the order A, B, and C. Similar examples of this condition would be represented by the following notations:  $A+60^\circ B^-/\infty$ ;  $\infty/B-30^\circ C^-$ ;  $A+20^\circ C^-/\infty$ .

The plane of section shown in text-figure 1f might be described as "a laterally placed, longitudinally cut section, lying approximately halfway between the axis of growth, or centre line, and the side of the test, and cutting only the last ten of the thirteen chambers present in this specimen of *Monogenerina*." In terms of this system it is simply and somewhat precisely defined by the notation  $\frac{1}{2}/\infty/\infty$ . Similarly, the oblique attitudes of the planes of section in text-figure 1h and text-figure 1i can be defined as  $\infty/\frac{1}{2}/\frac{1}{2}$  and  $\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$ , respectively, without recourse to a lengthy descriptive identification which might prove of little value in later work.

Whilst this method has obvious advantages of conciseness and moderate accuracy, the following points should be borne in mind during its application:-

- 1) The position of the axes must be fixed arbitrarily and clearly defined in the case of each genus or geometric form.
- 2) The method is merely a conventional notation, introduced solely to avoid lengthy descriptions and to achieve a greater measure of precision than is possible under present terminology.
- 3) Although similar in form to the concept of parameters in solid geometry and to certain conventional symbolism in crystallography, this method lacks the mathematical significance of the former and differs in intent from the notations of the latter.
- 4) Unit distance is purely conventional in concept and has no actual linear value. Hence it may differ in measurement not only between species of the same genus, but often between individuals of the same species.
- 5) Similarity in the notation of sections from different specimens does not necessarily indicate a similarity of form. Thus, in text-figure 3 Bj and Cj, the  $\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$  section of *Cribrostomum* differs markedly from the  $\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$  section of *Climacamina*.
- 6) In an assemblage in which different ontogenic stages of the same species occur, the same notation may indicate two differing sections in an adult and a juvenile, or conversely, the same form in section may have two different notations, depending upon the ontogenic stage of the two specimens. Thus, in text-figure 3, the juvenile stage of a specimen of *Cribrostomum*, cut in  $0/\infty/\infty$ , would appear as in text-figure 3 Ac, whilst the adult stage, also cut in  $0/\infty/\infty$ , would show the form of text-figure 3 Bc (see Cummings, 1956).
- 7) This system of notation cannot be applied to specimens that have undergone crushing or distortion, either prior to fossilisation or during the later diagenetic history of the host sediment. It may be noted that whilst such features are common in the foraminiferal faunas of British Upper Palaeozoic shales (Cummings, 1955, p. 222), they are relatively rare in the limestones and indurated sediments in which the greater part of thin-section analysis is to be undertaken.

In the case of the Palaeotextulariidae, the positions of the axes are shown in text-figure 3, and may be defined for the various genera as follows:

*Palaeotextularia* (text-figure 3 Aa and Ab):

A-axis - passing through the origin at right angles to C and lying in the plane of the zig-zag biserial suture.



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B-axis – passing through the origin at right angles to the A- and C-axes.

C-axis – a line passing through the centre of the proloculum, approximating the axis of growth, and lying in the plane of the zig-zag biserial suture.

*Cribrostomum* (text-figure 3 Ba and Bb):

Axes similar to those of *Palaeotextularia*, with the C-axis emerging on the inner marginal area of the final apertural face.

*Climacammina* (text-figure 3 Ca and Cb):

A- and B-axes as in *Palaeotextularia*.

C-axis – the line passing through the centres of the proloculum and the final apertural face.

*Cribrogenerina* (text-figure 3 Da and Db):

Axes similar in arrangement to those of *Climacammina*. Position of A-axis readily defined in tests possessing a biserial initial portion, but otherwise fixed arbitrarily in relation to the apertural pattern.

*Deckerellina* (text-figure 3 Ea and Eb):

Axes similar in arrangement to those of *Palaeotextularia*, with the A-axis lying in a plane parallel to the bases of the double aperture.

*Deckerella* (text-figure 3 Fa and Fb):

Axes similar in arrangement to those of *Climacammina*, with the A-axis lying in a plane parallel to the bases of the two apertures on the terminal face.

*Palaeobigenerina* (text-figure 3 Ga and Gb):

Axes similar in arrangement to those of *Climacammina*.

*Monogenerina* (text-figure 3 Ha and Hb):

Axes similar in arrangement to those of *Cribrogenerina*, with the position of the A-axis fixed arbitrarily.

Although this method of notation is introduced and illustrated with particular reference to the Palaeotextulariidae, it can be applied to any geometric form, and is used extensively in all the Upper Palaeozoic foraminiferal studies of the current revision. Thus, in the case of the Archaediscidae, the A-axis is the axis of coiling of the final whorl; the B-axis is drawn at right angles to both the A- and C-axes; and the C-axis is a line through the origin to the centre-point of the aperture and at right angles to the A-axis.

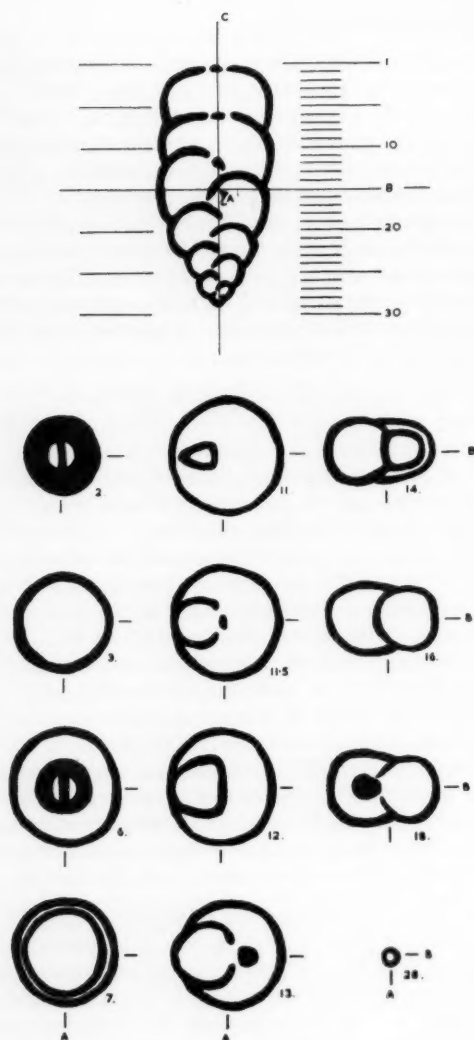
### Analysis of three-dimensional form

Before the identification of random foraminiferal thin sections from any stratigraphic horizon of indurated rocks can be attempted, a complete review of the internal test-morphology of each genus of the group under consideration must be carried out on "solid" specimens from adjacent layers of more friable sediments. This review should cover both adult and juvenile stages of typical species, and of any others which show a significant difference of geometric form. It should include a reconstruction of the shape and appearance of selected specimens in various planes of section.

After the population analysis of specimens from a washed shale sample has been carried out, a representative "solid" foraminifer is selected as typical of a particular species-variant, and the positions of the A-, B-, and C-axes identified. By use of the technique described by Cummings (1950), the specimen is mounted in transparent resin, which, after hardening, is cut into a block whose surfaces are at right angles to the axes of the specimen. With the Croft Parallel Grinder, the foraminifer is then ground down, in successive stages, parallel to the plane of the A- and B-axes and along the C-axis. A record of the morphology of the section is made by taking a cellulose pull (Cummings, 1952) at each stage, and the axial positions are marked on these pulls. Usually the stages are cut at 0.05 mm. intervals along the C-axis, but the distance may vary depending upon the size of the specimen, the complexity of the internal structure, and other factors.

Once a complete series has been taken through a specimen, the cellulose pulls are photographically enlarged, traced on graph paper in consecutive order, and arranged with the A-axes parallel. From this serial record it is possible to reconstruct the form which the "solid" specimen would have had in any plane of section, and to identify that plane using the axes as datum lines.

Text-figure 2 illustrates the analysis of a specimen of *Deckerella* measuring about 1.5 mm. in length along the C-axis, prepared in thirty regular stages at 0.05 mm. intervals, these stages being numbered from 1 to 30 consecutively. Five additional stages were interpolated at various points to assist in the reconstruction of apertural form (for example, the stage marked 11.5), but their positions are not shown on the grid. The variable form of the stages is illustrated by a selection of twelve from the total of thirty-five, viz., nos. 2, 3, 6, 7, 11.5, 12, 13, 14, 16, 18, and 28. By plotting the intercepts of the test wall along the B-axis at successive stages and in



TEXT-FIGURE 2

Diagrams showing twelve representative stages from the thirty-five prepared by serial-sectioning of a specimen of *Deckerella* sp. from the Lower Limestone Group, Scottish Lower Carboniferous. The upper diagram shows the reconstruction of the 0/∞/∞ section beside the grid of thirty normal stages. All diagrams  $\times 25$ .

relation to the known intervals between these stages on the C-axis, the form of the 0/∞/∞ section can be constructed, as shown in the upper part of text-figure 2.

This technique provides a complete review of the internal morphology to be used in the identification and description of the species population from which

the "solid" specimen is selected. It also indicates a precise method of identifying the random thin sections of this species occurring in adjacent indurated rocks. By so doing, this technique makes it possible to partially integrate the evidence from the two types of host sediment and so to achieve a fuller and more accurate account of faunal sequences.

In many of the families of the foraminifera, including the Palaeotextulariidae, the internal morphology is limited in pattern within each genus. The differences between similar sections of the constituent species of a particular genus are therefore minor in character. Nevertheless, this technique is adequate to indicate a large number of these minor variants when carried out in full.

#### Relationships of types of section to biocharacters

Although there are an infinite number of possible planes of section through any one foraminifer, all of these may be grouped into a certain small number of types. Each type contains sections showing morphological similarities and variable information concerning the same set of biocharacters. Any plane through a member of the Palaeotextulariidae falls into one of ten broad types. These may be identified by the notation of a particular plane which shows the features common to the type. Thus, in the palaeotextulariids, the most important sections are those of the 0/∞/∞ type (see text-figure 3), and the other types of lesser importance may be identified by the planes  $\infty/0/\infty$ ,  $A+45^\circ B+/\infty$ ,  $\infty/\infty/0$ ,  $\infty/B+45^\circ C+$ ,  $\frac{1}{2}/\infty/\infty$ ,  $\infty/\infty/\frac{1}{2}$ ,  $\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$ ,  $\infty/\frac{1}{2}/\frac{1}{2}$ , and  $\frac{1}{2}/\frac{1}{2}/\infty$ .

The similarities to be found within a type are brought about by an interplay of the attitudes of the various planes and the morphology of the single oriented specimen. The latter may be considered as a summation of various conditions of the several biocharacters present in its particular phyletic group. Hence there is a very close relationship between the type of section and the biocharacter. The individual sections within each type reveal a variable amount of morphological detail concerning a certain grouping of biocharacters. Furthermore, this grouping will differ between types, the detail of a biocharacter being revealed in one and not in another.

The relationships between types of section and biocharacters in the Palaeotextulariidae is summarised in text-figure 3. Each individual of this particular family is a combination of varying conditions of test shape, chamber arrangement, chamber form, sutural form, septal form, peripheral contouring,

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surface ornamentation, wall structure and composition, apertural form, apertural sequence, and other biocharacters (see Cummings, 1956). The relationships between these biocharacters and the ten types of section is summarised below, and leads to an evaluation of present analytical techniques in foraminiferal studies of indurated material. (The letters given in parentheses in the succeeding part of the text refer to the appropriate diagram in text-figure 3.)

1)  $0/\infty/\infty$  type: Since this type of section reveals the maximum amount of morphologic detail in the case of the palaeotextulariids, it proves to be the most valuable type in their identification in thin section. Although presenting an accurate representation of test shape, it fails to distinguish between cylindrical and compressed tests (Cc and Cd). The arrangement and number of the chambers are revealed in the fullest detail, but their actual form is only partly revealed, there being no evidence of their horizontal extent. The nature of interchamber sutures is shown by depression, overlap, etc., at each side of the test, but the character of the biserial zig-zag suture is never shown. Septal modifications in the vicinity of the chamber opening, which usually take the form of spatulate thickenings, as well as the general curvature of the septa, are indicated reliably; so, too, is the peripheral lobulation of the lateral extremities of the test. Diagenetic alteration of the host sediment frequently modifies the exterior surfaces (pl. 1, figure 6), and only rarely is the true nature determinable in this type. Normally, the wall-structure and composition of the lateral, upper and lower chamber walls are revealed in correct detail, and often the lateral buttressing, if this is present. The only distortion of thickness that may arise is in the septa, because of the sharp lateral curvature. The height of the aperture in biserial tests is normally correctly indicated, but in uniserial tests, apertural width may be more apparent than real because of the position of the aperture in relation to the plane of section (Bc and Ec). Since all apertural conditions are shown accurately, this type of section is extremely valuable in the determination of the sequence in ontogeny. Nevertheless, it must be noted that the regularly and irregularly cribrate forms cannot be distinguished, and often an asymmetrical arrangement of the final chamber, a feature frequently present in *Cribrostomum* (Bc), may lead to an incorrect interpretation.

2)  $\infty/0/\infty$  type: This type of section differentiates the cylindrical from the compressed shapes, whether these be together in the test (Cd) or present singly (Dd). The apparent irregularity of growth incre-

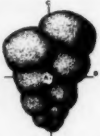























































ment (Ad) in biserial forms is due to the interplay of plane of section, chamber arrangement, and septal curvature. Whatever the chamber pattern may be, it shows in this type as apparently uniserial. True uniserial tests often have an appearance in this type that is identical with the appearance of their  $0/\infty/\infty$  type, particularly if the cross-section is circular and the form cylindrical (Dc and Dd). Although the true condition of a biserial test is always hidden by an apparent uniserial chamber arrangement, it can be identified by the alternation of large and small intrachamber areas (Bd), together with the seeming irregularity of growth increment. Since this type is cut in the position of septal overlap, it is possible in biserial tests to obtain some idea of the chamber form in the vestibular region only (compare Ac and Ad). Spherical, discoidal, and domed chambers can be distinguished in uniserial tests. The degree of overlap between the chambers is clearly indicated (Ed), as is the change from biserial to uniserial (Fd and Gd). Only in uniserial tests is the number of chambers accurately shown, for in the biserial test the number may be reduced by such factors as variability of septal overlap and the possibility of the plane of section passing through the position of the aperture. The latter situation is indicated usually by a break in the loop of the septal arch (Ad; compare with the third chamber of Ac).

The outline in this type of section gives some indication of compression along the zig-zag suture in biserial tests (Ed), and the shape of the septal arch is a direct reflection of septal form. When a thickening from the lateral parts toward the crest of the septal arch occurs in biserial forms, this may be due to a change of septal curvature operating on a wall of constant thickness (Ed). Alternatively, it may indicate an actual septal thickening in the vicinity of the aperture (Gd, and Gc in the late biserial portion). Apertures produce breaks in the septal arch (Ad and Bd), and their proximity is often shown by thinning of the arch toward the C-axis (as in the last chamber of Ed). The degree of septal overlap is directly related to the heights of the intrachamber areas along this axis (as in the biserial part of Gd). Uniserial tests exhibit the same septal form both in this type and in the  $0/\infty/\infty$  type of section.









































The only manifestation of peripheral lobulation in this type amongst biserial tests is that due to localised inflation about the zig-zag suture (Ed), and surface features are distorted by the effect of lateral inflation and septal curvature around the growth axis. A much truer picture of peripheral and external features, with little or no distortion, is given for uniserial tests.



CUMMINGS

GENUS	TYPICAL FORM		FORM IN ORIENTED THIN-SECTIONS				
	LATERAL VIEW	APERTURAL VIEW	$o/a/o$	$o/o/a$	$2a/a/o$	$a/a/o$	$o/a/a^+$
PALAEOTEXTULARIA A							
CRIBROSTOMUM B							
CLIMACAMMINA C							
CRIBROGENERINA D							
DECKERELLINA E							
DECKERELLA F							
PALAEOBIGENERINA G							
MONOGENERINA H							

# ANALYSIS OF SMALLER FORAMINIFERA

FORM IN ORIENTED THIN-SECTIONS				
$\frac{1}{2}/\infty/\infty - 1/\infty/\infty$	$\infty/\infty/\frac{1}{2}$	$\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$	$\infty/\frac{1}{2}/\frac{1}{2}$	$\frac{1}{2}/\frac{1}{2}/\infty$
 $1/\infty/\infty$ h.	 i.	 j.	 k.	 l.
 $1/\infty/\infty$				
				
				
				
				
				
				

TEXT-FIGURE 3

Chart showing the typical forms of the genera of the Palaeotextulariidae, together with the positions of their notational axes and their appearance in the selected planes definitive of the ten types of section. The horizontal rows refer to the genera: *Palaeotextularia* in row A, *Cribrostomum* in row B, etc. The vertical columns refer to the appearance in the selected plane of section:  $0/\infty/\infty$  in column c,  $\infty/\infty/0$  in column f, etc. Any individual diagram is therefore identified by double lettering: the  $\infty/\infty/\frac{1}{2}$  section of *Cribrogenerina* by "Di," etc. This chart is based on serial-section analyses of representative specimens, using the method of graphic reconstruction described in the text. In each case, the results have been confirmed by sectioning identical "solid" specimens directly to the illustrated selected plane. It should be noted, therefore, that the differing appearances of the sections in each horizontal row is not due to variation in material, but to the attitudes of the varying planes of section in relation to the single and individual specimen illustrated in columns a and b.

Septal curvature in the apertural region may lead to a slight variation in the optical properties of the wall structure and in the thickness, especially in species which possess a multilayered fabric. The true apertural form is exhibited only in uniserial cylindrical tests with a regularly arranged cribrate aperture (Dd) or a single central aperture (Hd). In irregularly cribrate uniserial conditions, the real form is seldom indicated (Cd), and in biserial tests the aperture is rarely shown, except in those instances where, by variability of septal overlap, the plane of section passes through the aperture or lies laterally to the chamber face (Ad). It follows that this type of section gives no indication of the true apertural sequence, apart from the two conditions noted above (Dd and Hd).

3)  $A+45^\circ B+\infty$  type: In many uniserial tests having a regularly arranged apertural form, whether it be single or cribrate, this type includes sections identical in appearance to those of the  $0/\infty/\infty$  type, and is therefore often difficult to recognise in such cases. Among biserial tests, a compressed shape is revealed by an apparent enhancement of the inequality of internal areas between paired chambers (Ae), whilst cylindrical tests show a form similar to that of the  $0/\infty/\infty$  type (compare stages in the early parts of Fc and Fe). Such a difference may show in one specimen, when there is a change in chamber character (Ce). The apparent irregularity of growth increment arises as a result of the interplay of apertural width, degree of septal overlap, and test compression operating in association with the attitude of the plane (Be).

Although chamber arrangement is reliably indicated throughout, the form of the chambers may not be represented accurately. Apparent distortion occurs in compressed forms (Ae), and often localised features of the vestibular region and aperture may lead to individual variations (absence of apertural break in the early part of Ee).

Sutural features are only partly revealed, although, by a comparison of the two sides of the section, an indication of the change in character from the lateral regions to the position of the zig-zag suture may be obtained in biserial tests (Fe). Similarly, changes in septal form and curvature at different points in biserial tests may also be noted (Fe). Surface features are not subject to any great distortion, and the variability of peripheral lobulation is given by a comparison of the two sides of the section.

In this type, the structure and thickness of the wall frequently exhibit irregularities. Usually these are

due to the combined effect of the plane of section and the curvature of the test components, rather than such features as local buttressing or the proximity of the zig-zag suture. Apertura! form is shown accurately only in uniserial forms with a single aperture (He) and in some uniserial forms having a regularly arranged cribrate aperture (De). Otherwise the representation is often very incomplete. Thus, only one aperture of the regularly cribrate condition is shown in the final chamber of Be; or again, apertures are not shown in the early biserial part of Ge, a common occurrence in this type of section. It follows that the apertural sequence is never adequately shown, except perhaps in the two instances noted above and typified by He and De.

4)  $\infty/\infty/0$  type: This is often referred to as the transverse section, and, in the case of the palaeotextulariids, is common in thin sections cut at right angles to the bedding planes. Although the  $\infty/\infty/0$  plane is taken as the indicatrix of the type, and the  $\infty/\infty/1/2$  plane is treated separately in text-figure 3, they are considered together in the present review.

This type of section shows the degree of rounding in the test shape. In the biserial pattern of chamber arrangement (Af, Bf, and Ef), it has an appearance which is different from that of the uniserial (Df, Gf), but does not indicate what combinations, if any, of these two conditions exist throughout the test. There is no indication of the number of chambers, and the evidence as to form is that of the horizontal plane at only one point on the C-axis, although the degree of chamber overlap in biserial portions is revealed (Af, Bf, and Ai).

Depression along the zig-zag suture, peripheral features, and surface characters are more or less correctly indicated, but here again, the evidence is confined to that of a particular point on the C-axis, and hence is of little systematic value. When the section cuts the median part of a chamber, the structure and thickness of the wall are portrayed accurately (Df). At other positions they appear distorted due to the effect of wall and septal curvature (increasing thicknesses in Fi and Gi). In Cf, the relative increase in thickness of the inner chamber wall is due to the proximity of the apex, whereas the outer ring, being cut in the median part of the later chamber, approximates the true thickness.

Usually there is no indication of apertural form, and hence this type of section is valueless in so far as the sequence is concerned. Very rarely, a break in the section may show the position and width of the aperture (Ef and Bi), and even more exceptional



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are sections which reveal the inner cribrate shield of an earlier chamber, as in Ci.

5)  $\infty/B+45^\circ C+$  type: Whatever the form of the palaeotextulariid, this type of section exhibits an apparent irregularly uniserial pattern, or, in a very few cases, appears as a single elongate loop with lateral indentations.

There is no clear guide as to test shape, although some suggestion of compression (Ag) or of a cylindrical character (Cg) may be obtained by examination of the central region. However, such distinction is difficult and often unreliable. Whether it represents a biserial test (Ag and Bg), one with biserial and uniserial portions (Cg), or one which is wholly uniserial (Hg), this type of section always shows an apparent irregularly arranged uniserial chamber arrangement. Rarely, the inclusion of one wall loop within another (Fg) identifies a biserial condition. The form and number of the chambers are never revealed, and any attempt at an interpretation of sutural, septal, or peripheral features from this type is valueless.

The structure of the wall may be identified, including any lateral buttressing, which appears as lunate patches on the inner surfaces. The thickness, however, is shown accurately only along one line in the section, that of the position of maximum chamber width. Elsewhere a variable distortion due to wall curvature is present (Cg). Although commonly absent, the aperture, if single, may show as a break in a loop (Ag), or may be revealed as cribrate (Dg), or may be indicated by a mere incurving of the wall (Cg). No assessment of the apertural sequence can be made from this type.

6)  $\frac{1}{2}/\infty/\infty$  type: This includes the plane  $1/\infty/\infty$ , which is more typical in some cases. As a type, it is likely to result in a considerable amount of misinterpretation, and, in the past, has often led to incorrect systematic descriptions. The appearance of a biserial palaeotextulariid in the  $\frac{1}{2}/\infty/\infty$  plane (Ah) resembles in many ways that of the  $0/\infty/\infty$  plane through such a genus as *Trepeilopsis*. Again, in uniserial palaeotextulariids, it has been misidentified in several cases as the  $0/\infty/\infty$  type, with resultant errors in species descriptions (De and Dh). It is possible in all cases, however, to identify sections of this type and to distinguish them from those of the  $0/\infty/\infty$  type.

Usually there is an indication of the general test shape, such as the difference between tapering (Ah) and cylindrical (Dh) specimens. If it is sharply tapering, however, the early part of the test may be

absent in the section (Ch), and in many cases local areas of solid wall material are produced in the initial parts as a result of the taper (Ah, Eh, and Fh). Wholly biserial and entirely uniserial conditions are distinguishable (Ah and Dh). When the test is a combination of these two conditions, usually only the uniserial is shown (Ch), although rarely there may be included a mere suggestion of the biserial part when the degree of taper is relatively low (Fh and Gh). Chambers having a distinctly inflated form may be identified by the presence of gaps in the inner parts of the section (Ah), or by marked re-entrants in the earlier portions (Ah and Eh). The number of chambers is never shown accurately, since the early portion is missing in all cases (Bh and Dh).

The pronounced indentations on the sides of this type of section are not a true indication of sutural form, there being an exaggeration as a result of the lateral position of the plane. Depression along the zig-zag suture is indicated by a re-entrant in the earlier part (Ah and Fh) and by frequent gaps in the inner regions of the section (Ah and Bh). If these gaps were misconstrued and were looked upon as intrachamber areas, the specimen might be misinterpreted as having a tubular or trochospiral form. Septal, peripheral, and surface features are indicated inadequately.

The wall structure is shown in a low tangential plane. When areas of solid material are exhibited in the earlier part of the section, these often prove valuable in the analysis of structure. The thickness of the wall is subject to great distortion in this plane. The form of the aperture is seen rarely and only in those cases in which a widely scattered cribrate condition is present (Bh, Ch, and Dh). Accordingly, no information can be gained concerning apertural sequence in this type.

7)  $\infty/\infty/\frac{1}{2}$  type: The relationships between biocharacters and this type of section are illustrated in text-figure 3 (A-H/i), and have been discussed above in the consideration of the  $\infty/\infty/0$  type, with which this is almost synonymous.

8)  $\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$  type: In some instances this type might be misinterpreted as  $0/\infty/\infty$ , but the significant differences are outlined below.

This type of section produces a large number of apparent minor irregularities in test shape, yet the general form can be determined in most cases. For example, the tapering of Aj is distinct from the cylindrical character of Dj. The chamber arrange-

ment is shown not only in wholly biserial tests (Aj and Ej) and in wholly uniserial tests (Dj and Hj), but also in those possessing both conditions (Cj, Fj, and Gj), the latter by the asymmetry and localised thickening of the wall in the earlier parts of sections. The number of chambers shown is never complete and is always reduced to a degree dependent on the taper of the test. In biserial specimens the apparent irregularity of growth increment (Bj) does not give a true picture of chamber form, and in uniserial specimens there is a tendency for the taper to be exaggerated (Cj). Sutural, septal, peripheral, and surface features are all subject to distortion. The variable character of the wall structure often seen in this type may be due almost entirely to the attitude of the plane rather than to intrinsic structure (Cj). The same is true of the thickness, especially in the initial stages of biserial tests when the chambers are represented by solid areas of wall material (Ej and Hj). Even when an aperture is present in a section of a biserial specimen, its form may be only apparent (Ej), and it is usually distorted in uniserial tests, especially those with a cribrate condition (Cj). As a result, the apparent apertural sequence may be very misleading; the change from climacaminoid to deckerelloid in Cj is due entirely to the interplay of the plane of section and a cribrate apertural condition, which is seen in Cc to be climacaminoid throughout the uniserial portion.

As indicated above, there is a prevalent danger of misinterpretation in this type. Thus, Aj might be regarded as near to the  $0/\infty/\infty$  section of a megalo-spheric palaeotextulariid, but the absence of an aperture in the first chamber of the section belies such an interpretation. Again, Dj might be regarded as a  $0\infty/\infty/$  section of a *Cribrogenerina*, but the localised thickening in the early part and the pattern of apertural sequence serve to identify it as belonging to the  $\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$  type.

9)  $\infty/\frac{1}{2}/\frac{1}{2}$  type: Although common, this type is of little value, and can be used in only a few instances for reliable systematic and stratigraphic work. True test shape is seldom exhibited, although indications of taper (Ck) and of compression (Ak) may be given. Whilst all tests appear uniserial in this type, those having a biserial pattern may be identified by the alternation of larger and smaller intrachamber areas (Ak and Ek). As in Dk, the uniserial condition often shows an exaggeration of taper which may lead to confusion with the  $0/\infty/\infty$  type, although this error can be avoided in the particular example by noting the absence of apertures. The change from a biserial to a uniserial mode of growth can frequently be detected by a change from a circular or subcircular

form of chamber loop to one with an ellipsoidal or rectangular appearance (Ck and Fk). General chamber form is indicated accurately in uniserial tests (Ck and Dk) but never in biserial tests, and the total number of chambers is never revealed. Little reliable information is to be gained concerning the morphology of the septa, sutures, and periphery. The effect of the obliquity of the section on the wall-structure and thickness is marked, and the latter shows a high degree of apparent variability. Usually, apertural form is not shown in biserial tests (Ak), but parts of apertures are often visible in uniserial specimens (the last chambers of Bk and Dk). As a result, no estimate of apertural sequence is possible.

10)  $\frac{1}{2}/\frac{1}{2}-/\infty$  type: This is an extremely common type of section, which has but limited value and whose identity is revealed by a marked asymmetry in the early part of the test. The general shape is indicated, whether it be biserial (Al), uniserial (Dl), or a combination of both (Fl). It should be noted that a biserial chamber arrangement in the initial portion is often indicated by a strongly asymmetrically aligned series of apparently uniserial chamber loops (Cl). Usually most of the chambers are present in the case of uniserial tests (Dl), but the biserial are represented by one of each pair, arranged in the asymmetrical fashion noted above (Cl and El). The main features of chamber form, sutures, septa, surface, and periphery are moderately well shown. Whilst the general character of ten wall structure is determinable, the asymmetry often allowing for an interpretation of any internal buttresses, the thickness tends to be exaggerated over most of the section. Apertural form is detectable only occasionally in biserial tests (Al), although it may be indicated in part at localised positions (the later chambers of Bl). It is partially displayed in uniserial specimens, but never in its full development (Cl and Dl). Any attempt to interpret the apertural sequence must be inaccurate, therefore, and in such regularly cribrate uniserial forms as Dl is liable to misinterpretation.

This review reveals the intimate relationship that exists between the biocharacters and the type of section. Details of the condition of a particular biocharacter are indicated to a varying extent by the different types of section. From one type it may be possible to obtain a complete description of the condition of the biocharacter, from another only a partial description, and from a third no information whatsoever. The results of this review are summarised below in terms of how much information it is possible to gain from each of the ten types of section concerning each of the main palaeotextulariid biocharacters:

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BIOCHARACTER	TYPE OF SECTION									
	1	2	3	4	5	6	7	8	9	10
Shape of test	0	+	0	+	/	0	+	0	/	0
Camber arrangement	●	/	0	/	/	+	/	0	/	+
Number of chambers	●	+	●	-	-	/	-	+	-	+
Chamber form	+	/	+	+	-	+	+	/	/	+
Sutural form	+	+	+	/	/	+	/	/	/	+
Septal form	0	/	+	+	-	/	+	/	/	/
Peripheral features	+	+	+	+	-	/	+	/	/	+
Surface features	0	/	0	/	/	/	/	/	/	+
Wall structure	●	0	0	0	0	+	0	0	0	0
Thickness of wall	0	+	+	/	/	/	/	/	/	+
Apertural form	0	+	+	/	/	/	/	/	/	/
Apertural sequence	0	/	/	-	-	/	-	/	-	/

● = Complete details of the condition of the biocharacter visible.

0 = Most of details visible.

+

/ = Some details visible.

- = Few or no details visible.

Types of section numbered to correspond with descriptions given in the preceding section.

This review leads to two important conclusions. Firstly, no single type of section shows the complete details of the condition of every biocharacter present in the specimen. Secondly, some types yield a greater amount of detail than others. Thus, the  $0/\infty/\infty$  type yields the maximum morphologic detail in the Palaeotextulariidae, but even so it fails to provide a complete picture of test structure. Furthermore, there is a vast difference in the amount of detail to be gained from the  $0/\infty/\infty$  type and the  $\infty/B+45^\circ C+$  type. Since it is possible to prepare a similar review for any group of smaller foraminifera, these conclusions are not to be confined to the Palaeotextulariidae, however, but are general in character and universally applicable.

When these results are considered in relation to generic and specific determinations, it follows that systematic identification based on single and random thin sections in indurated rocks is unreliable. Depending upon the interplay of section type and biocharacters, some determinations to family rank may be possible, and a few to generic rank may also be achieved. Rarely, if ever, can a reliable specific identification be made on the basis of a single random thin section.

This assessment may be exemplified by the Palaeotextulariidae. The identification of a solid specimen as belonging to this family requires certain morphologic details concerning the conditions of two major biocharacters, the wall structure and the chamber arrangement. The same is true of a random thin section. Yet the required amount of information is provided only in certain types of sections, viz.,  $0/\infty/\infty$ ,  $A+45^\circ B+/\infty$ ,  $\frac{1}{2}/\infty/\infty$ ,  $\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$ , and  $\frac{1}{2}/\frac{1}{2}/-\infty$ . Only in such cases can the section be identified reliably as a palaeotextulariid.

To attempt a generic determination of any accuracy, it is necessary to know details, not only of wall structure and chamber arrangement, but also of apertural form and sequence. The only random thin sections of palaeotextulariids which provide sufficient information are those of the  $0/\infty/\infty$  type, with the maximum being supplied by the  $0/\infty/\infty$  plane itself. Hence this is the only type of section in which a reliable generic determination can be made.

To identify correctly the species to which a given section should be referred requires the maximum morphologic detail concerning the conditions of all biocharacters. No single type of section is adequate for these needs, although sometimes there may be one which approaches the requirements. Thus, the  $0/\infty/\infty$  section indicates the condition of most palaeotextulariid biocharacters and may suggest, therefore, the species to which a particular section belongs. But such indications are by no means conclusive, and normally it is impossible to identify random thin sections to specific rank with any measure of reliability or finality.

It is possible to conceive of a species possessing a unique condition of one biocharacter which might be exhibited in several types of section, allowing immediate specific determination. A pronounced vestibular apparatus in the final chamber might characterise a species of *Palaeotextularia*. Because it is visible in the  $0/\infty/\infty$ ,  $A+45^\circ B+/\infty$ ,  $\frac{1}{2}/\frac{1}{2}/\frac{1}{2}$ , and possibly  $\frac{1}{2}/\frac{1}{2}/-\infty$  types, this character would make it possible to identify, without further preamble, any such sections of this species that might occur. Although this is not an entirely hypothetical postulate, no such examples have been met with in the present study.

The limitations illustrated in this assessment have been overlooked in many foraminiferal studies, yet they seriously restrict the stratigraphic application of these microfossils in indurated rocks. At the present time, there are two procedures aimed at overcoming these limitations or reducing their effect. The first of these, widely employed in Soviet micro-



palaeontology, is to build up the concept of a morphospecies from the numerous randomly cut fragments found in limestone thin sections. The second procedure obviates the need for specific determination by the use of the bioseries method in stratigraphy; in this case, the type of section which provides the maximum information on the selected biocharacter is used, and the condition of that biocharacter at successive stratigraphic horizons is examined.

Both procedures require more than one section, their efficacy being directly related to the amount of material employed. In the following discussion of their relative merits, a partial integration is suggested. This is based largely on the concept of the bioseries, but incorporates some of the features of the other method, including systematic nomenclature in certain cases. This technique further improves the reliability of the results and offsets the limitations outlined above.

#### The assemblage and species identification

No matter what procedure is adopted, the fundamental necessity of studying the assemblage remains. Only by population analysis and by consideration of all biocharacters can a specific determination of any accuracy be achieved. This applies equally to assemblages of "solid" specimens from friable rocks and to those of randomly cut fragments occurring in limestone thin sections from samples of the same or adjacent horizons.

In the case of "solid" specimens, techniques of assemblage-study are widely known and have been applied in a variety of ways, the one used in the current revision of Upper Palaeozoic foraminifera being described by Cummings (1956). In contrast, in the published accounts of Upper Palaeozoic foraminifera based solely on thin-section analysis, there is little appreciation of the assemblage or of variability. In these studies, there has been a tendency to adopt the procedure of selecting a single sectioned fragment which reveals a considerable amount of morphologic detail as the norm of a species; of grouping within this arbitrarily typified form all other sectioned fragments which the author considers to belong to the morphospecies; and of describing and naming this form on the basis of the collated information. Such a practice is open to major inaccuracies. Not only are the limits of the species-assemblage defined subjectively, but there is little objectiveness in the grouping of the fragments. There is no method of reconstructing a specimen's "solid" form from a single thin section, nor does

similarity of appearance in section always indicate identity of morphology. This has been demonstrated in detail above.

At the present time, the only way to offset these limitations seems to be a partial integration of the two methods of analysis, with serial-section technique and population analysis of the "solid" species assemblage being used to identify and delineate its spread in indurated rocks. This contention is illustrated by the palaeotextulariid material shown in text-figure 4, in which diagrams based on randomly cut sections from several horizons in the British Lower Carboniferous show the differing appearances of members of species assemblages in thin section.

With "solid" specimens collected from an adjacent level of friable rocks, it is possible to demonstrate by serial-section technique that all the sections exhibited in Series A of text-figure 4 belong to one species of *Climacammina*. The approximate attitudes of the various planes are: No. 1,  $\frac{3}{4}/\frac{1}{2}/\frac{3}{4}$ ; no. 2,  $4/6/\frac{1}{2}$ ; no. 3,  $\frac{1}{2}/\infty/\frac{3}{4}$ ; no. 4,  $\frac{1}{2}/3/1$ ; and no. 5,  $\frac{1}{2}/4/\frac{3}{4}$ . If each is considered singly, no. 1 does give some indication of the climacaminoid condition, but nos. 3, 4, and 5 suggest the palaeotextularioid type of chamber arrangement, and no. 2 seems to have little or no relationship to the palaeotextulariids. It is very doubtful that such a grouping of this species assemblage could be made without recourse to the suggested technique.

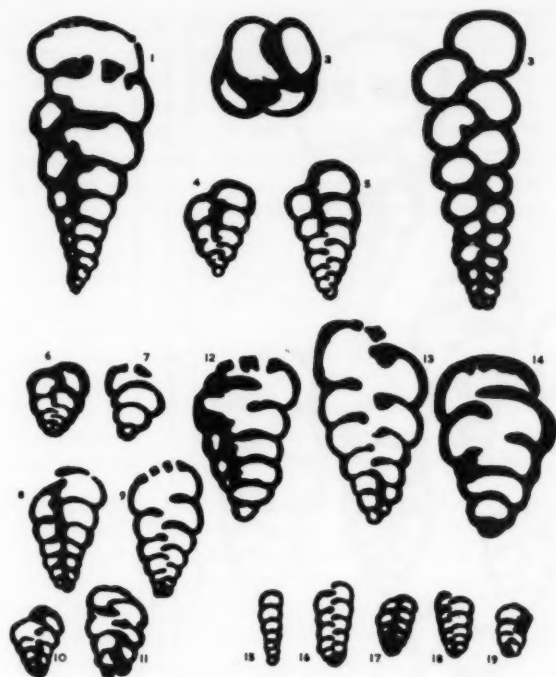
In a similar manner, it can be demonstrated that each of the other series in text-figure 4 belongs to a particular species assemblage. In Series B the cribrostomoid condition is revealed in no. 9, but the apparent deckerelloid apertural form in nos. 7 and 8 might prove misleading, and the chamber arrangements in nos. 6, 10, and 11 give no real indication of the true cribrostomoid pattern.

The apparent differences of wall thickness in Series C are due entirely to the varying planes of section, and not to intrinsic variation in this species of *Cribostromum*. No. 13, approximating a  $\frac{1}{4}-/\infty/\frac{1}{2}$  section and with an apparent deckerelloid apertural form in the final chamber, shows a wall thickness that is true in parts. On the other hand, the much greater thickness shown in no. 14 is due to its attitude, approaching  $2-/3/\frac{1}{2}$ .

The upper Tournaisian Series D is based on an assemblage of a common species of *Palaeotextularia*. The palaeotextularioid chamber arrangement is exhibited in nos. 16-19, and it is conceivable that these could be grouped together purely by subjective study. However, the apparent uniserial form



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TEXT-FIGURE 4

Diagrams of random thin sections of palaeotextulariid species-assemblages from various horizons in the British Avonian. Series A, nos. 1-5, selected randomly cut sections from an assemblage of one species of *Climacamina* present in a single thin section of limestone from the upper D<sub>1</sub> zone, upper Visean, South-West Province, British Lower Carboniferous. Series B, nos. 6-11, of one upper Visean species of *Cribrostomum* from the D<sub>1</sub> zone of the South-West Province. Series C, nos. 12-14, of one upper Visean species of *Cribrostomum* from the same locality and horizon as that of Series B. Series D, nos. 15-19, of one upper Tournaisian species of *Palaeotextularia* from the C<sub>1</sub> interval of the North-West Province, British Lower Carboniferous. All of these groupings have been checked by serial-section analysis of "solid" specimens in adjacent friable horizons. All diagrams  $\times 24$ .

of no. 15, a  $\infty/\frac{1}{2}/1$ -section, might lead to misinterpretation. If considered alone and without this objective check, it could be regarded as a member of some such uniserial group as the Earlandiidae.

It may be concluded, therefore, that the only reliable method of studying and identifying groups of foraminifera in indurated rocks is by an extension of the concept of species assemblages from neighbouring friable host sediments. Furthermore, if taxonomy is to be meaningful, the limitations of the

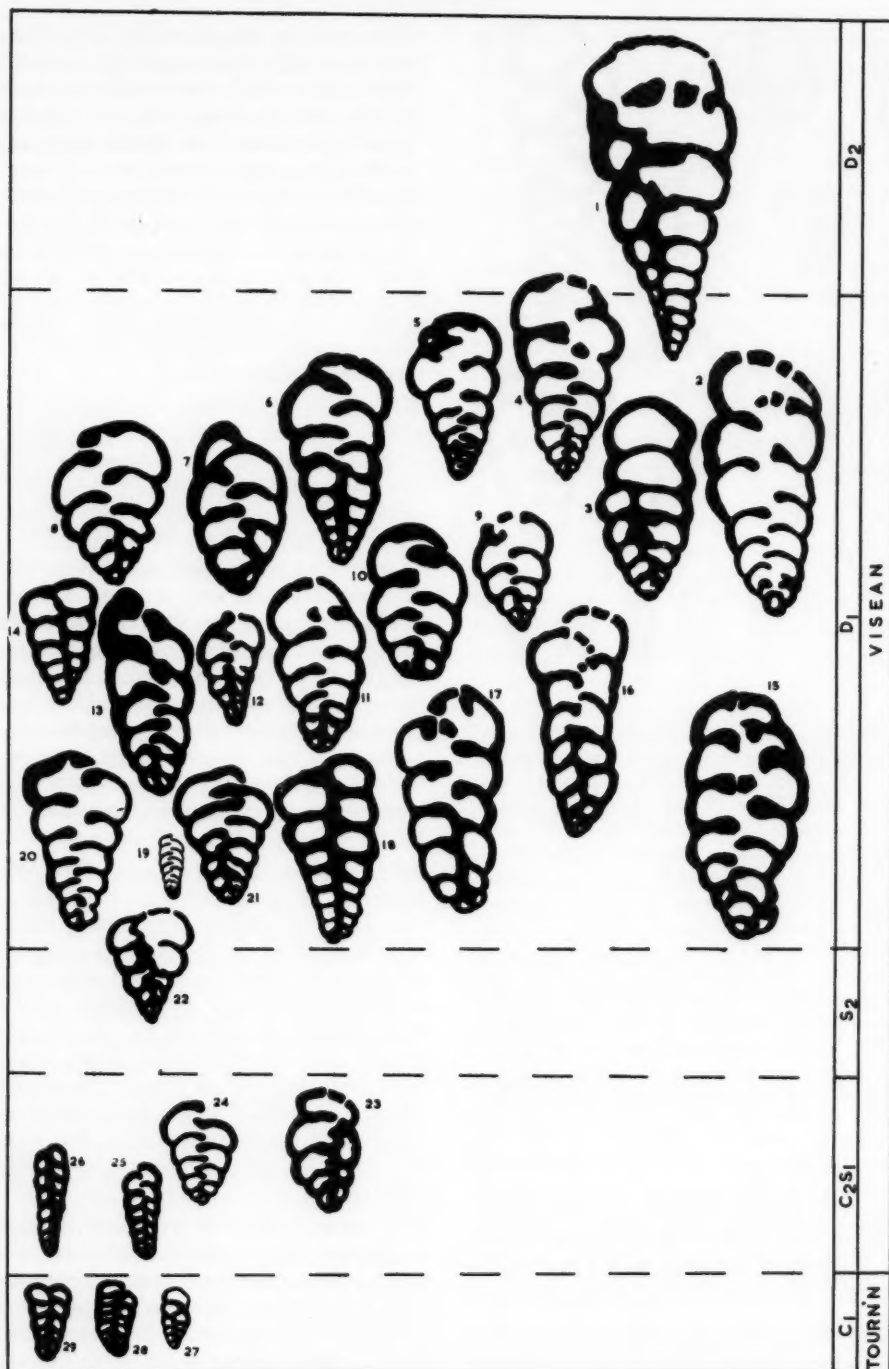
study must be recognised. It is for this reason that systematic identification in the current revision of Upper Palaeozoic foraminifera is confined to a definite pattern. Only in the case of assemblages of "solid" specimens from friable horizons, and only in those instances where it is possible to extend the results into adjacent horizons of indurated rocks, are species named and described. More commonly, identification in thin-section analysis is limited to family and generic determinations, with the emphasis in stratigraphic work on morphogeny and bioseries rather than on the absolute range of morphospecies.

## Morphogeny and thin-section analysis

The use of the bioseries in stratigraphy is widespread, and it is a procedure which does partly offset the limitations inherent in thin-section analysis. As an expression of change through time, the bioseries is developed from a study of the morphogeny of a particular biocharacter as revealed by its condition at successive levels. Sequential population analyses of assemblages, as well as serial sectioning, can be used to determine this morphogeny in soft rocks. In indurated rock successions it is customary to delineate this morphogenetic pattern by selecting one or more types of section which exhibit the maximum information concerning the condition of the biocharacter, and to study the changes in detail throughout the stratigraphic sequence. Usually it is convenient to summarise the bioseries in chart form.

As an example of such a chart, text-figure 5 shows a summary of palaeotextulariid morphogeny in the Avonian of the British South-West Province. Based almost entirely on thin-section analyses, it differs only in detail from the general phylogenetic pattern described previously (Cummings, 1956). The sections illustrated belong to three types,  $0/\infty/\infty$ ,  $\frac{1}{2}/\infty/\infty$ , and  $A+45^\circ B+\infty$ . These types yield the maximum amount of detail concerning the condition of several biocharacters, including the three that are of major importance, the wall structure, the chamber arrangement, and the apertural sequence.

This chart, which is a typical example of such summaries, illustrates several bioseries within the family. There is a gradual increase in size from the top of the Tournaisian to the uppermost Visean, and this is demonstrably independent of lithologic facies. Though there is an overall modification of test shape, cylindrical forms becoming increasingly abundant at higher levels, its effect is partly masked by differences in outline due to dimorphism. The bioseries of chamber arrangement shows the intro-



TEXT-FIGURE 5

Diagrammatic chart showing the morphogeny of the Avonian Palaeotextulariidae of the British South-West Province, based on selected randomly cut thin sections from indurated rocks. All diagrams  $\times 32$ .

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duction of the uniserial mode within the  $C_2S_1$  interval and a gradual elaboration upward in the Viséan. This is accompanied by concomitant development of apertural variation, with the establishment of the multiple and cribrate conditions. Although slight and localised variations occur in the bioseries of wall structure, the general overall conservatism indicates the validity of the family grouping.

Whether considered singly or together, these bioseries have distinct stratigraphic value. The occurrence of a uniserial pattern indicates a post-Tournaisian age. If an assemblage contains uniserial palaeotextulariids that are large and varied in form, then it may be identified as belonging to the  $D_1$  interval. Furthermore, such age-determinations can be carried out on the basis of thin-section analysis alone.

Nevertheless, here again the limitations must be recognised. The application of the bioseries in stratigraphy is a reliable routine method of age determination, providing the initial study that established the bioseries was developed from "solid" specimens as well as from thin-section analysis. In addition, these summaries must be confined to a consideration of the more general features, for many of the differences in detail shown in such charts are more apparent than real.

The seemingly planispiral initial portions of nos. 15 and 17 in text-figure 5 (see also pl. 1, figure 3) are not intrinsic structures but are both due to the interplay of the plane and the initial curvature of the test in biserial specimens. The single apertural break in the final chambers of no. 15 and figure 12 in plate 1 are partial expressions of truly cribrate forms. In no. 20 (pl. 1, figure 7), the double aperture of *Deckerellina* is not exhibited in full. The reasons for the apparent thickening of the wall in nos. 13 and 18 (pl. 1, figure 2) have been given previously.

In the upper Tournaisian specimen shown in no. 27 of text-figure 5, the final chamber appears to have a uniserial attitude. Similar sections were formerly interpreted (Cummings, 1956) as having been cut from tests that were uniserial in the final chamber. Hence, *Cribrostomum* was described as a genus that appeared for the first time in the upper Tournaisian (text-figures 5, nos. 22 and 23; see also Cummings, 1956, p. 238). At that time, full verification was impossible because "solid" assemblages of this age were not available. More recently, "solid" assemblages have been obtained from contemporaneous deposits. These assemblages show that no. 27 and similar sections are not so derived. They are sections of a  $\frac{1}{2}/\frac{1}{2}/\infty$  alignment cut through a species of

*Palaeotextularia* that possesses an enlarged final chamber. Hence, the uniserial chamber pattern is now believed to have appeared in the  $C_2S_1$  interval of the Viséan, and *Cribrostomum* is regarded as a post-Tournaisian genus.

This correction emphasises the likelihood of error in those cases in which thin-section analysis alone is used in the initial delineation of the bioseries. It indicates the need for an integrated method, in which assemblages from both hard and soft host sediments are used.

### STRATIGRAPHIC APPLICATION

Problems attendant upon the stratigraphic use of Upper Palaeozoic smaller foraminifera are not confined wholly to actual faunal analysis, but also arise from the nature and distribution of the host sediments. Techniques employed in Mesozoic and Kainozoic studies must be modified for use in the Palaeozoic.

#### Nature of the British Avonian

Accumulated in localised troughs, amidst and around a sinking land mass, the British Avonian sediments exhibit rapid lateral changes of facies and thickness, often with major differences of succession between one area and another. The distinctive character of each province has been enhanced further by their partial isolation into tectonic basins during the country's later geologic history.

These fundamental characteristics of isolation and differing sequences have proved to be major factors in the pattern of British Lower Carboniferous research during the past fifty years. The necessity for an initial detailed survey of each individual area has led to the emphasis of that area as a unit, manifest in the widespread adoption of such terms as the South-West Province, North-West Province, etc. Since most of these initial detailed studies are now completed, the stage has been reached where it is possible to concentrate on problems of regional correlation and its synthesis throughout the British Isles.

An original faunal sequence was established by Vaughan (1905) in the South-West Province. In this sequence, the successive assemblages of corals and brachiopods in the calcareous facies were outlined. Although he related these assemblages to lithology, Vaughan nevertheless regarded them as biozones, and they have been looked upon as the British standard since their inception. Most workers have attempted to correlate other areas with this standard by direct comparison of the sequence of

mixed faunal assemblages in the calcareous facies, and less commonly by the use of the absolute range of individual coral and brachiopod species. This practice has met with indifferent success in many cases, and has brought the value of Vaughan's work into question.

Paradoxically, it is the practice, rather than Vaughan's study, which is at fault. The sequence of mixed faunal assemblages in any one area, even when confined to the calcareous facies, is the mutual expression of the evolutionary pattern of the stocks present and the influence of differing and successive environments. There are many distinct environments within the calcareous facies. These are expressed not only in the lithologic variety of limestones and calcareous shales, but also in the particular groupings of the various stocks present in the contained assemblages. The coral-brachiopod zonation is a sequence of biofacies in the Bristol area, and not a sequence of biozones with regional application. Using his own terminology, Vaughan's zones are really "phases" within the limestone environment, as suggested by the adoption of such terms as the "*Caninia phase*" (Oswald, 1955). This identifies the biofacies of the *Caninia* zone of the Bristol succession when it is present in other areas and at other horizons. To attempt regional correlation with this standard is impracticable, therefore, in view of the great variety of British Lower Carboniferous facies and sequences.

Vaughan's study retains a twofold value outside the immediate neighbourhood of Bristol, however. On the one hand, it initiated detailed faunal studies in the Avonian, and, on the other hand, it suggested that a possible basis of stratigraphic correlation lay in the fauna of the calcareous facies. Marine limestones and shales occur in all areas, although at varying horizons, and usually yield an abundant and diverse fauna. These provide a common feature from which a general British biochronology may be developed.

But this can be achieved only by the adoption of a new approach to Avonian stratigraphic problems. The present practice of matching mixed faunal sequences from different areas must be abandoned, since it frequently leads to the misidentification of a biofacies as the characteristic assemblage of a biochron. Improvement is possible only by the selection of a particular zoological group present in the calcareous facies and by preparing a complete analysis of this group's behaviour at all horizons and in all areas. Such an approach stresses the time factor and is not subject to over-influence by the

stratigraphic features of local areas. It assesses the full effect of environment and determines the phylogeny, on which all stratigraphic correlation must be based, with the greatest accuracy. One of the ultimate objects of the research outlined in this current series of publications is to apply the smaller foraminifera in British Upper Palaeozoic stratigraphy along these lines.

Nearly all studies of faunal correlation in the British Lower Carboniferous have been based on macrofossils, particularly corals, brachiopods, and goniatites. This is explained partly by the lack of intensive micropalaeontological activity in this country, and partly by the controlling effect of the nature of the Avonian sediments. By far the greater part of these are indurated limestones and sandstones, which required specialised analytical techniques to be developed before their foraminiferal content could be of value in stratigraphy. Even though foraminifera were recorded in such rocks by Buckland (1841) and Phillips (1849) and their presence noted by Brady (1876), no serious attempt has been made to employ them until this current review was begun. Again, it is only in the British upper Visean that abundant "solid" assemblages are to be found in the friable calcareous shales. For this reason, most of Brady's original work (1876) was confined to the faunas of higher horizons, using specimens collected singly in the field by moistened brush and hand-lens! Recent work has shown that "solid" assemblages occur at lower horizons but are rarer and more difficult to extract. It is against such a background that the following procedure has been developed.

#### Application in the British Avonian

*Traverse lines:* Since most of the British Lower Carboniferous has been mapped in detail, it is usually possible to select in each major region one or more collecting traverses which readily include the greater part of the succession. These require the maximum surface exposure of the rock sequence, if possible a continuous one. Two excellent localities for the siting of such type-traverses are the Avon Gorge (Vaughan, 1905) and Burrington Coombe (Reynolds and Vaughan, 1911), in the South-West Province.

*Collection:* In Upper Palaeozoic strata, collection must be as complete as conditions allow, if the best results are to be obtained. Hence, the sequence must be sampled along the type-traverses bed by bed, with simultaneous logging of macrolithology, thickness, and structural attitude. No individual bed is too small to be overlooked, for it may indicate some fundamental environmental change during depo-



## ANALYSIS OF SMALLER FORAMINIFERA

sition. Often a friable layer half an inch in thickness will yield an assemblage of "solid" specimens which provide the sole foundation for an extensive series of thin-section analyses extending over many feet. Again, in the larger units, particularly limestones, the sampling interval should never exceed five feet or thereabouts, for a minor lithologic change within the mass of the bed and not indicated by subsidiary bedding may be of great faunistic importance.

The type of sample is determined by the consolidation of the host sediment. In indurated rocks it is sufficient to collect an oriented hand-specimen some twenty cubic inches in volume, marked with the attitude of the bedding plane. In friable material, at least sixty cubic inches must be collected. Such soft-rock samples should be duplicated, in certain instances, one sample being of weathered material and one of unweathered, since weathering often enhances earlier diagenetic factors in microfaunal preservation (Cummings, 1955). It is often desirable to collect samples of both types from the same horizon whenever conditions permit. Where igneous intrusions have led to contact metamorphism of adjacent sediments, the accompanying mineralogical changes may be a revealing factor in the interpretation of foraminiferal wall structure, and hence these should not be overlooked.

*Preparation of material:* Indurated rocks are prepared by cutting thin sections of the normal type. At least twelve square inches of section area are required for examination, the greater part being cut parallel to the bedding planes and the remainder at right angles to this.

Friable material is broken down by the boiling-water, hydrogen peroxide, or more rarely petroleum techniques, and the residues separated by washing on sieves down to 240 mesh/inch screen size. Thereafter the residues are hand-picked.

*Faunal analysis:* The pattern and controlling factors of faunal analysis have been outlined above. Repeated testing of material from one horizon, the material being treated at one time as "indurated" and at another as "friable," has shown that the quantitative results from a thin-section twelve square inches in area are approximately similar to those obtained from sixty cubic inches of friable material. Fracture and loss of microfaunal content in soft rocks during sample preparation largely explains the initial disparity of volume.

When this factor and practice of collection is used, it is possible not only to determine the absolute range of individual species and genera, as well as the

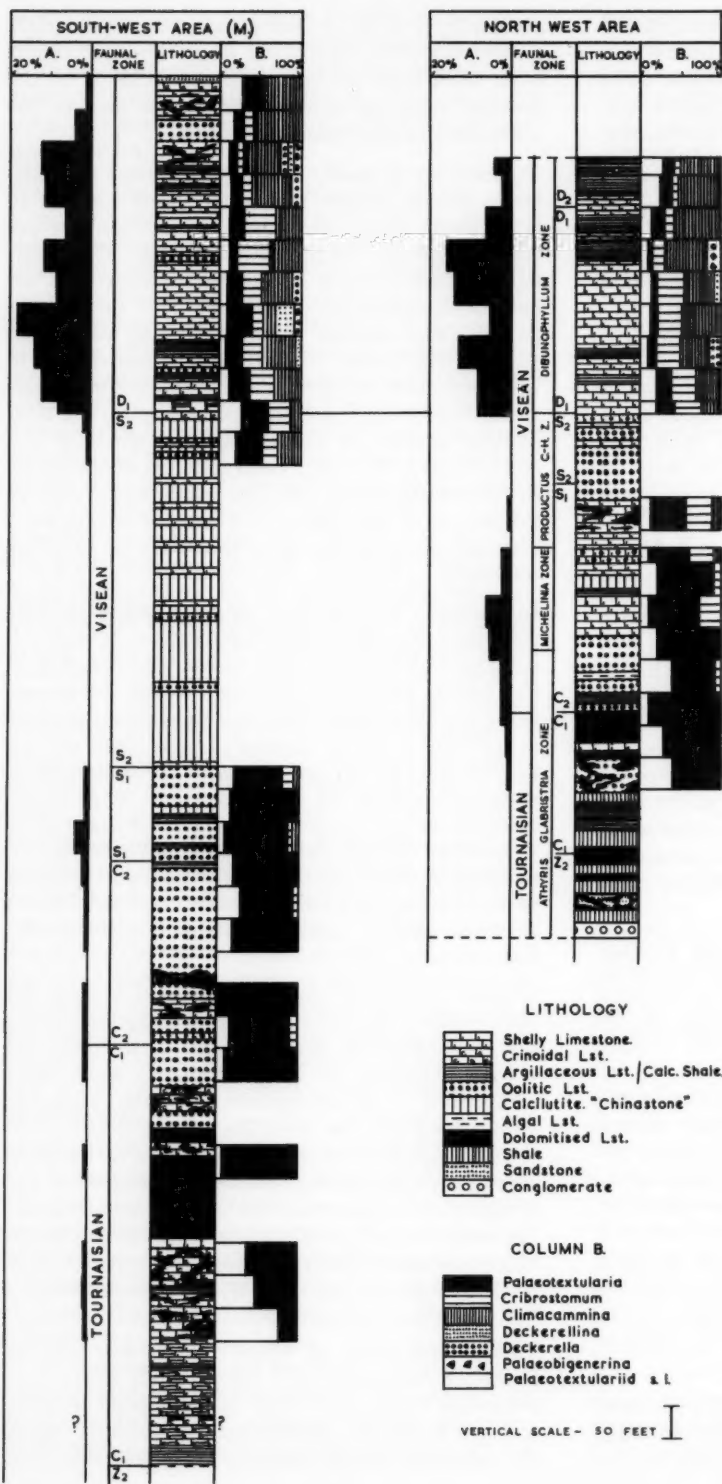
morphogeny of the various groups, but also to attain almost complete integration of quantitative results from both types of host sediment. This is of the greatest value in general correlation and in the assessment of the influence of facies.

*Representation of results:* The representation of qualitative results follows the widely used method of constructing range charts, in the case of the absolute range of species and genera (Cummings, 1956, text-figs. 22 and 23), and diagrammatic charts, in the case of morphogeny (text-figure 5 of the present paper). The method of summarising integrated quantitative results is illustrated in text-figure 6. The proportion of individuals referable to a particular group can be expressed as a percentage of the total number present in the assemblage, whatever the actual figures may be. The results so obtained for the palaeotextulariids of two areas are shown in Column A of text-figure 6. Here the values have been simplified by averaging the results for fifty-foot intervals.

In contrast, the proportional distribution of individuals of one family within its various genera can be expressed as percentages of the total number of the family present in the assemblage, allowance being made for those fragments to which no generic determination can be applied. This is illustrated for the Palaeotextulariidae in Column B of text-figure 6, where the values are again averaged for fifty-foot intervals, except in a few cases. The plotting of these two values against the detailed lithologic log and macrofossil zonation reveals fundamental features of distribution and palaeoecology, especially when charts of different areas are compared, as in text-figure 6.

Column A exhibits the same general pattern for both areas. The palaeotextulariids appear for the first time about the middle of the  $C_1$  interval, and extend upward in the Tournaisian, forming a small component of the foraminiferal faunas. They exhibit a local maximum in the middle of  $C_2S_1$ , but then tend to become very rare, and are frequently absent in  $S_2$  assemblages. About at the base of  $D_1$ , however, there is a very rapid influx, and throughout the lower part of the upper Visean they form an important assemblage-component (pl. 1, figs. 1-8, 10-12). As the base of the Namurian is approached, this importance diminishes.

This pattern is by no means due to any obvious facies-control expressed in the lithology of the host sediments, although it may be influenced by such ecologic factors as temperature and salinity, whose variations are petrographically unrecognisable. The



TEXT-FIGURE 6

Quantitative distribution charts of the Palaeotextulariidae in two widely separated areas of the British Avonian: a, the Mendips District of the South-West Province, with macrofaunal zones based on Reynolds and Vaughan (1911) and Welch (1929 and 1933), and summarised from the Burrington Coombe and Holcombe Quarry traverses; b, the Shap District of the North-West Province, with macrofaunal zones based on Garwood (1912), and summarised from the Shap Abbey-Docker Beck traverse. *Note:* New collecting traverses reveal details of lithology from thin-section analyses which are not always in agreement with the succession as stated in the reference cited.

## ANALYSIS OF SMALLER FORAMINIFERA

local maximum in the  $C_2S_1$  interval occurs in a dominantly oolitic facies in the South-West Province, whereas it appears at the same horizon in the North-West in a shelly limestone lithology. Its simultaneous occurrence in other areas is often in facies different from those listed here.

It is true that the dearth of palaeotextulariids in the  $S_2$  rocks of the Mendips may be due to the diagenetic effect of redistribution during the production of the secondary "chinastone" lithology (pl. 1, figure 13). Destruction of microfaunal content by redistribution is well known (Cummings, 1955), and in text-figure 6 the effect of secondary dolomitisation is illustrated in the middle  $C_2$  interval of the South-West Province. But this rarity occurs also in a dominantly oolitic facies of the same age in the North-West, and is demonstrable in a variety of facies at this horizon in other areas.

Since the conditions of deposition were of constant and widespread character in the D zone of the British Avonian, it is difficult to decide how far facies-control affects the prominent influx of palaeotextulariids at the base of this zone. What variety of lithology there is in the lower D interval seems to have little or no accompanying variation in the pronounced abundance of the group.

The pattern of Column B is equally valuable in stratigraphy. Not only does it show the absolute range of the genera, but it also demonstrates their quantitative occurrence. The upper Tournaisian is characterised by the dominance of *Palaeotextularia*. The appearance of *Cribrostomum* at the base of the Viséan, and its upward replacement of *Palaeotextularia* is, in turn, transitional to the dominance of *Climacamina* in the D zone, after the latter's initial appearance in the upper  $C_2S_1$  interval. The other genera are limited to small representations in the upper Viséan. Local maxima of fragments which cannot be determined generically, often because of their condition of preservation, frequently occur at levels of shales or secondary dolomitised limestone. In the case of the former, this is usually due to crushing during diagenesis (pl. 1, figure 11), and in that of the latter to redistribution.

### SUMMARY OF PROCEDURE

The need for an integrated analytical method and its development, as well as its value in stratigraphy and palaeoecology, have been demonstrated. The sequential pattern of the method is summarised below:

- 1) Selection of collecting traverses in relation to the geology of the area.
- 2) Collection of material from traverses, and notation of lithology, thickness, structural attitude, etc.
- 3) Maceration of samples and preparation of assemblages from friable rock material.
- 4) Analysis of these assemblages by population studies, etc., leading to systematic identification.
- 5) Serial sectioning of norms and end-members of scatters within the assemblages.
- 6) Analysis of hard-rock faunas by microscopic examination of thin sections, with recognition of:
  - a) the inherent limitations;
  - b) the integrative effect of comparison with the results of serial-sectioning;
  - c) the pattern of the bioseries;
  - d) the partial systematic identification.
- 7) Summarising of the results of the analyses made in steps (4) and (6), by:
  - a) range charts showing the absolute distribution of genera and species;
  - b) diagrammatic charts showing the outline of morphogeny and/or phylogeny;
  - c) quantitative distribution charts of each particular group.
- 8) From such charts, a final assessment of the stratigraphic value and distribution of the various groups as well as the influence of environment on their occurrence.

This procedure is often laborious and time-consuming. By its use, however, the inherent limitations of other methods can be taken into account, and its integrative nature ensures a high degree of accuracy.

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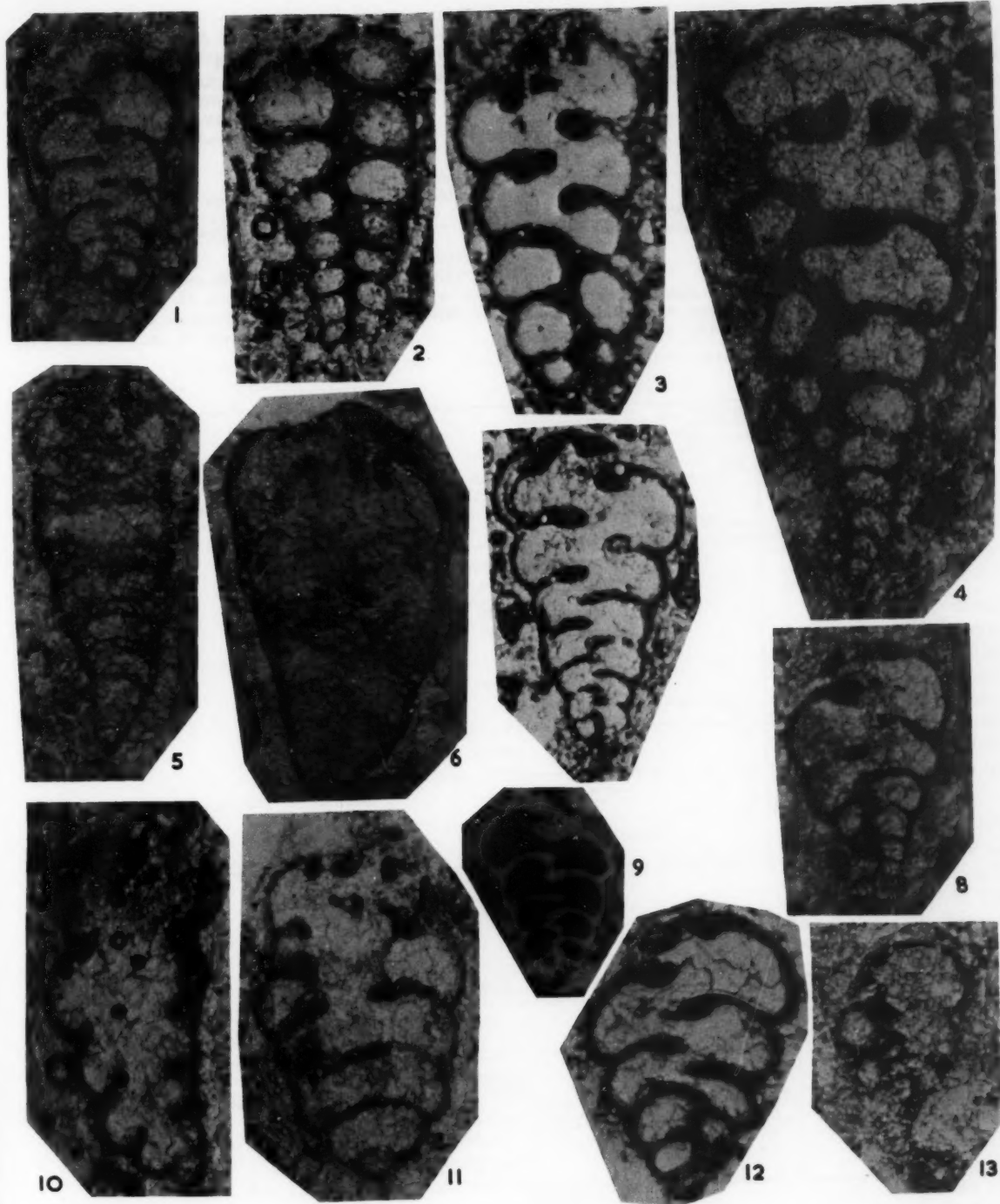
CUMMINGS

PLATE 1

All figures  $\times 55$ .

- 1 *Cribrostomum* sp.  
A typical form from the lowermost D<sub>1</sub> subzone, Lower Carboniferous, of Holcombe Quarry, Mendips, Somerset, England.
- 2 Biserial palaeotextulariid ( $\frac{1}{2}/\infty/\infty$  section)  
Shows apparent thickening of the wall in this plane of section. Lowermost D<sub>1</sub> subzone of Holcombe Quarry.
- 3 *Climacammina* sp. ( $\frac{1}{8}/\infty/\frac{1}{2}$  section)  
Shows apparent planispiral coiling in the early portion. Lower D<sub>1</sub> subzone of Holcombe Quarry.
- 4 *Climacammina* sp. ( $\frac{3}{4}/\frac{1}{2}/\frac{3}{4}$  section)  
Upper D<sub>1</sub> subzone of Holcombe Quarry.
- 5 Palaeotextulariid fragment  
Shows alteration during recrystallisation of the host sediment. D<sub>1</sub> subzone of Holcombe Quarry.
- 6 *Climacammina* sp.  
Shows resorption of internal structure and alteration of external surface. D<sub>1</sub> subzone of Holcombe Quarry.
- 7 *Deckerellina* sp. (A+5°C+/ $\infty$  section)  
Shows faint indications of the double apertural condition. Lower D<sub>1</sub> subzone of Holcombe Quarry.
- 8 *Climacammina* sp.  
Shows destruction of the apertural region in the penultimate chamber. D<sub>1</sub> subzone of Holcombe Quarry.
- 9 *Palaeotextularia* sp. (0/ $\infty$ / $\infty$  section)  
Typical form of the lower Visean. Michelinia zone, Lower Carboniferous, of Kendal, Westmorland, England.
- 10 *Climacammina* sp.  
Shows resorption of internal features. D<sub>1</sub> subzone of Holcombe Quarry.
- 11 *Climacammina* sp.  
Shows crushing during diagenesis. D<sub>1</sub> subzone of Holcombe Quarry.
- 12 *Cribrostomum* sp. ( $\frac{1}{2}/2/\frac{1}{2}$  section)  
Shows very slight indications of cribrate aperture. D<sub>1</sub> subzone of Holcombe Quarry.
- 13 *Cribrostomum* sp.  
Shows test destruction by secondary recrystallisation. Uppermost S<sub>2</sub> beds, Lower Carboniferous, of Burrington Coombe, Somerset, England.





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# HORNIBROOK

N.Z. FORAMINIFERAL ZONES AND SOME O					
Compiled by N. de B. Hornibrook N.Z. Geological Survey for the					
NEW ZEALAND	N.Z. FORAMINIFERAL ZONES		INDONESIA	SAIPAN	
SERIES	STAGES	Pelagic	Benthic	letter stages	(Todd, Cloud, Low, Schmidt)
HAWERA					
WANGANUI	25 CASTLECLIFFIAN				
	24 HUKUMARUAN		Miocene species mostly died out		
	23 WAITOTARAN				
	22 OPHITIAN	Recent Planctonic assemblage appears	Some Miocene Species persisting		
TARANAKI	21 KARITEAN				
	20 TONGAPORUTUAN		<i>Bolivinita quadrilatera</i> (Schw.) appears		
SOUTHLAND	19 WAIUAN		Last Orbitoids, <i>Tryblolopina</i> , <i>Cyclotylpeus aff. lineopacificus</i> var. <i>terheerri</i> Tan.	<i>Bolivinita quadrilatera</i> appears in Nagai, (fide Belford & Kicinski) last orbitoids, <i>Nephrolepidina</i> , <i>Tryblolopina</i> , <i>Cyclotylpeus indo-pacificus</i> var. <i>terheerri</i> Tan.	upper
	18 LILLBURNIAN	<i>Orbulina universa</i> Abdt.			f
	17 CLIFDENIAN	<i>Orbulina universa</i> ? <i>O. suturalis</i> appears.	<i>Tryblolopina</i> , <i>Cyclotylpeus aff. postoides</i> Tan, <i>Nephrolepidina</i>	<i>Cyclotylpeus postoides</i> Tan	lower
	16 ALTONIAN	<i>Globigerinoides baphegus</i> (Todd) appears	<i>Miogykina intermedia</i> , <i>Nephrolepidina</i> (common), <i>Cyclotylpeus</i> , <i>Eulopina</i> , <i>Tryblolopina</i> (rare)	<i>Eulopina</i> , <i>Miogykina</i>	upper
PAREORA	15 AWAMOAN	<i>Globigerinoides triloba</i> Reuss appears. <i>Globorotalia miaozei</i> Fik. (aff. <i>terheerri</i> )			e
	14 HUTCHINSONIAN				
	13 OTAIAH		<i>Nephrolepidina</i> (appears)	<i>Nephrolepidina</i> appears	lower
LANDON	12 WAITAKIAN	<i>Globorotalia dehiscens</i> appears			d
	11 DUNTHOONIAN		<i>Rotalitina sulcigera</i> last appearance (rare)		c
	10 WHANGAROAN		<i>Rotalitina sulcigera</i> (Stadel) Abdt.		
ARNOLD	9 BUNANGAN	<i>Globigerinoides index</i> (last appearance), <i>Hantkenina aff. alabamensis</i> (quadrata, fide) last appearance, last <i>Globigerinella</i> stage	<i>Asterocyclina</i> last appearance <i>Colletes</i> last appearance <i>Nummulitella</i>		b
	8 KAIATAN		<i>Discocyclinidae</i>		<i>Hantkenina</i>
	7 BORTONIAN	<i>Globigerinoides index</i> fm. appears <i>Hantkenina australis</i> fm. (aff. <i>alabamensis</i> )	<i>Rotalitina sulcigera</i> appears		<i>Globorotalia centralis</i>
DANNEVIRKE	6 PORANGAN				
	5 HERETAUNGAN	earliest <i>Globigerinella</i> stage <i>Globorotalia</i> ( <i>Truncorotalia</i> ) crater fm. aff. <i>velascoensis</i> last appearance			
	4 MANGARAPAN	<i>Globorotalia</i> ( <i>Truncorotalia</i> ) crater fm. (S.S.) aff. <i>velascoensis</i>	<i>Asterocyclina speighti</i> (Chap.) <i>Aragonia zelandica</i> fm. (aff. <i>aragonensis</i> ), <i>Colletes</i>		d
	3 WAIPAWAN	first <i>Globorotalia</i> ( <i>Truncorotalia</i> ) <i>Discoaster nuttallatus</i> <i>Brometta</i> and <i>Rieda</i>			
MATA	2 TEURIAN	<i>Globigerina</i> aff. <i>triloculata</i> -oides appears	<i>Larostoma lissimma</i> (Calk.) <i>Bolivinita delicatula</i> (-) <i>Neorhabdina thalmonii</i> (fm.) (aff. <i>severiculator</i> Calk.) <i>Bullimina kirkpatricki</i> Calk.		
	1 HAUMURIAN (New Stage proposed by Wellson, 1956)	large <i>Gumbelina</i> <i>Gublerina glauca</i> var. <i>Globotruncana</i> , small beaded <i>Rugoglobigerina</i>	<i>Neorhabdina rakurakana</i> fm. (aff. <i>reticulata</i> (Reuss)) <i>Bullimina incrasata</i> (Reuss) <i>Bullinoides darreni</i> fm. <i>Bullimina kirkpatricki</i> Calk.		

TABLE 1

ZONES AND SOME OVERSEAS EQUIVALENTS											
Handbook N.2. Geological Survey for the 1957 ANZAAS meeting at Dunedin											
INDONESIA	SAIPAN	TRINIDAD B.W.I.	CHILE	MEXICO	EGYPT	ISRAEL	EUROPEAN EQUIVALENTS				
(Stages in the field)	(Todd, Cloud, Low, Schmidt)	(Cushman, Benz, Steinforth)	(Todd & Knicker)	(White & Hutton)	(Said & Kanawy)	(Reiss)					
							SICILIAN	PLEISTOCENE			
							CALABRIAN				
							ASTIAN-PLAISANCIAN	PLIOCENE			
							PONTIAN	MIOCENE	U		
							SARMATIAN				
							TORTONIAN				
							HELVETIAN				
							BURDIGALIAN	L			
							AQUITANIAN				
							CHATTIAN	J			
							RUPELIAN				
							LATTORIAN	L			
								M	OLIGOCENE		
								U			
								M	Eocene		
								L			
								PALEOCENE			
								CRETACEOUS			



**ABSTRACT:** *On the basis of foraminifera, New Zealand Upper Cretaceous and Tertiary stages are correlated with the international time scale as follows: Haumurian with Maestrichtian; Teurian with Danian; Waipawan with Paleocene; Mangaorapan and Heretaungan with Lower Eocene; Porangan and Bortonian with Middle Eocene; Kaiatan and Runangan with Upper Eocene; Whaingaroan and Duntroonian with Lower Oligocene; Waitakian with Middle Oligocene; Otaian with Upper Oligocene (Chattian); Hutchinsonian and Awamoan with Upper Oligocene or Lower Miocene; Altonian with Lower Miocene (Aquitanian); Clifdenian with upper Aquitanian or Burdigalian; Lillburnian and Waiauan with Middle Miocene; Tongaporutuan and Kapitean with Upper Miocene; Opoitian and Waitotaran with Pliocene. There is as yet no microfaunal evidence for the Pliocene-Pleistocene boundary in New Zealand. Some pelagic foraminifera described by Finlay from New Zealand are refigured, and notes, including descriptions and a proposal of a new species of Paleocene Globigerina are appended.*

## New Zealand Upper Cretaceous and Tertiary foraminiferal zones and some overseas correlations\*

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### INTRODUCTION

New Zealand, situated as it is on the western margin of the circum-Pacific mobile belt, has had a long history of vigorous crustal movement. During the Upper Cretaceous and Tertiary, a considerable thickness of sediment accumulated both in small-scale geosynclinal troughs and in marginal areas inundated by widespread marine transgressions. The total thickness of the Tertiary, although varying greatly in different diastrophic provinces, is of the order of 30,000 feet.

Continual tectonic activity persisted throughout the Tertiary, culminating in the Pliocene and Pleistocene with an episode of intensive folding accompanied by emergence of wide belts of marine Cretaceous and Tertiary rocks, strongly folded or broken into fault blocks. As a result, considerable areas of thick Cretaceous and Tertiary strata are well exposed in many continuous sections through both geosynclinal and marginal deposits.

The history of the New Zealand microfaunas is mainly one of partial isolation and development of a large endemic benthic faunal element including such typically New Zealand genera as *Notorotalia*, *Haeuslerella*, *Semivulvulina* and *Siphotextularia*, supplemented by species with much wider distribution.

\*Read at the Australian and New Zealand Association for the Advancement of Science meeting at Dunedin, January, 1957.

During the Upper Cretaceous, New Zealand shared with other parts of the world many of the Tethyan forms, although even at this time the endemic nature of the microfauna was already pronounced. Throughout the Paleocene and early Eocene, the resemblance of New Zealand microfaunas to the deep-water faunas of Central and South America and the Caribbean is very marked, and it persists into the Oligocene.

New Zealand Miocene microfaunas, which are of a distinctly warm-water type, have quite marked affinities with both Indo-Pacific and Central American assemblages, although these relationships are balanced by a strong endemic element. The Pliocene and Pleistocene are marked by the extinction of Miocene species, probably the result of a cooling climate.

The first descriptions of New Zealand microfaunas were made in 1864 by Stache and Karrer, on the basis of collections made by the Novara Expedition. Later contributions were made by Chapman, Parr, Kreuzberg, Cushman, Dorreen, Vella, and especially by Finlay, whose publications from 1939 to 1947 contributed very largely to the subdivision of the Upper Cretaceous and Tertiary into the twenty-five stages used by the New Zealand Geological Survey for the past ten years (see Table 1). Several additional subdivisions of the New Zealand

Cretaceous, including the new Haumurian stage, have been proposed recently by Wellman (1956).

New Zealand's situation, remote from the type areas of the European divisions of the Upper Cretaceous and Tertiary, greatly increases the difficulty of correlating the local subdivisions with the international time scale. A full account of previous attempts to correlate the New Zealand Cretaceous and Tertiary with beds of similar age elsewhere cannot be given here. Finlay and Marwick (1940, pp. 82-97) summarized both macrofaunal and microfaunal evidence in their paper on the divisions of the New Zealand Upper Cretaceous and Tertiary, and Finlay (1947b) fully discussed the foraminiferal evidence for trans-Tasman correlation of the Tertiary. Later, Dorreen (1948) contributed to the correlation of the New Zealand Eocene, and Hornibrook and Harrington (1957) to the knowledge of the Cretaceous-Tertiary boundary. Hornibrook (1953) gave an analysis of the effects of immigration on the New Zealand microfauna. Allan (1956) has ably summarized the criteria for circum-Pacific correlation.

An attempt to extend paleontological datum planes over long distances involves the basic concepts of paleontological correlation very clearly delineated by Allan (1948, 1956). Three categories of paleontological evidence are available: (1) Rapid spread of vigorously evolving forms, pelagic organisms appearing to have a great advantage; (2) vigorous evolutionary trends in already widespread groups; and (3) sudden world-wide extinction of previously well-established groups. The first two categories obviously require continuous avenues for dispersal, such as that provided by the Tethys sea until the early Tertiary, after which there was a decided tendency toward biogeographic provincialism in marine faunas. How far the terms of the third category are actually fulfilled is somewhat problematical; not all paleontologists believe in the sudden extinction of *Globotruncana* at the end of the Maestrichtian (Bettenstaedt and Wicher, 1955, pp. 514-516), and of *Hantkenina* at the end of the Eocene (Thalman, 1942).

Direct correlation of the New Zealand Tertiary with that of Europe by means of microfaunas is very difficult because of the long distances involved. The best hope of correlation appears to lie in the study of pelagic species in intermediate areas, particularly around the Pacific, in view of the advances in the knowledge of their distribution in the past few years (Grimsdale, 1951; Hamilton, 1953). Three lines of approach offer the most promise: (1) Correlation of

New Zealand Lower to Middle Tertiary microfaunas with those of Central America, especially Trinidad; (2) correlation of New Zealand Middle Tertiary microfaunas with those of the Indo-Pacific; and (3) correlation with special emphasis on pelagic foraminifera.

The present paper attempts to reassess the microfaunal evidence for correlating the New Zealand beds with the uppermost Cretaceous and Tertiary overseas. Exact equivalence of New Zealand stages with overseas units is not claimed. There is little likelihood that a stage characterized by a particular episode in the faunal history of one part of the world would have an exact counterpart in another, so that systems of local biostratigraphic units based on local faunal history are necessary for different regions.

Only those New Zealand species of direct significance in overseas correlation are dealt with in this paper; their local ranges are shown in Table 2.

#### DESCRIPTIONS AND CORRELATIONS OF STAGES

##### UPPER CRETACEOUS (MAESTRICHTIAN)

###### *Haumurian stage*

The microfauna of the Haumurian is very pronouncedly Cretaceous in character and includes such world-wide Maestrichtian forms as *Rugoglobigerina*, single-keeled *Globotruncana*, large *Gumbelina*, *Gublerina glaessneri* Bronniman and Brown, *Neoflabellina rakauoana* (Finlay), which is close to *Neoflabellina reticulata* (Reuss), *Bolivina incrassata* Reuss, and *Bolivina draco dorreani* Finlay, which also occurs in the upper Maestrichtian of Israel (Reiss, 1954). *Bulimina kickapoensis* Carsey and large *Rzehakina epigona* (Rzehak) are common. Furthermore, the Haumurian is marked by the highest occurrence of ammonites, belemnites and *Inoceramus*.

##### CRETACEOUS-TERTIARY BOUNDARY

###### *Teurian stage*

Teurian microfaunas include a strong Cretaceous element made up of many local species persisting from the Haumurian. Typical Maestrichtian forms are replaced by *Globigerina* of the *triloculinoides* type (*Globigerina linaperta* Finlay), *Globorotalia membranacea* (Ehrenberg), *Loxostomum limonense* (Cushman), *Neoflabellina thalmanii* (Finlay) (aff. *reticulata* Cushman), and *Bolivinaoides delicatula* Cushman. *Bulimina kickapoensis* and large *Rzehakina epigona* are common. A number of characteristically Tertiary lineages, including *Zeauvigerina*, *Aragonia* and *Nuttallides* aff. *trumpyi* (Nuttall) (*cretatumpyi* Finlay), balance the Cretaceous element.

###### *Waipawan stage*

Waipawan microfaunas differ from Teurian in lacking many local Cretaceous species and in the first appearance of a number of Tertiary lineages, including *Globorotalia* aff. *crassata aequa* Cushman and Renz (see pl. 1, figs. 1-2), *Globorotalia* (*Truncorotalia*) aff. *velascoensis* Cushman, *Globigerina pseudoiota* Hornibrook, n. sp., *Bulimina serratospina* Finlay, *Bulimina truncanella* Finlay (the last two species reported from the Lower Eocene of Israel by Reiss, 1952, p. 44), *Rectobolivina bortonica* Finlay, which is very close to *Loxostomum applinae* Plummer, of the

## NEW ZEALAND FORAMINIFERAL ZONES

upper Midway, and large ornamented *Vaginulinopsis*, *Vaginulinopsis waiparaensis* (Finlay). *Rzehakina* aff. *minima* Cushman and Renz is rare. *Tappanina glaessneri* (Finlay), which is close to *Tappanina selmensis* (Cushman), is restricted to the Waipawan. The Paleocene discoaster *Discoaster multiradiatus* has been reported by Bramlette and Riedel (1954) from the Waipawan.

Recent work on the Cretaceous-Tertiary boundary in the Middle East by Reiss (1952, 1954, 1955) in Israel, and by Said and Kenawy (1956) in Egypt, has thrown considerable light on the foraminiferal criteria for the Danian and Paleocene. Confirming Glaessner's earlier (1937a) work in the Caucasus, three successive zones were established by Reiss and by Said and Kenawy: a *Globotruncana* zone, a *Globigerina* zone (*triloculinoides* type), and a *Globorotalia* (*Truncorotalia*) zone. These same zones are represented in New Zealand, where they correspond to the Haumurian, Teurian and Waipawan stages. (A report of *Globorotalia crater* in the Upper Cretaceous of New Zealand by Hornibrook (1953, p. 437) is incorrect.) There can be little doubt that the *Globotruncana* zone is Maestrichtian, but the correlation of the two succeeding zones with European stages is complicated by the problem of the Danian-Montian relationships, which has recently been very fully reviewed by Nakkady (1957). He concluded that the Danian and Paleocene are at least partly equivalent, the upper Danian in many areas (although not the type Danian) being marked by a flood of *Globorotalia* (*Truncorotalia*). Reiss, and Said and Kenawy, on the other hand, correlated the *Globorotalia* (*Truncorotalia*) zone of the Middle East with the Paleocene. According to these workers, *Loxostomum limonense* (Cushman) and *Bolivina* *delicatula* Cushman are particularly characteristic of the Danian in the Middle East. Both are confined to the Teurian in New Zealand. However, these species occur in the lower part of the Velasco shale in Mexico (Reiss, 1955, p. 115), and they are found in the lower part of the Lizard Springs formation of Trinidad (Cushman and Renz, 1946), both occurrences apparently within the *Truncorotalia* zone (van den Bold, 1957, p. 3, table 1). Nakkady (1957, p. 432, table) includes them in the Danian. As a result of Brotzen's (1948) work on the foraminifera of the Swedish Danian and Paleocene, it has become generally accepted that the lower part of the Midway group (Kincaid formation) is a correlative of the Danian. Unfortunately, New Zealand Teurian and Waipawan microfaunas have little in common with the Midway except for *Rectobolivina bortonica* Finlay, which is very closely related to *Loxostomum applanae* Plummer of the upper Midway and which first appears in the Waipawan. The upper Velasco shale, with the first *Globorotalia* (*Truncorotalia*) *velascoensis*

(*vide* Grimsdale, 1951), appears to be the approximate age-equivalent of the Waipawan stage.

In the opinion of the writer, the microfaunas strongly indicate that the Teurian belongs to the Cretaceous and that the Waipawan is the base of the Tertiary. The problem involves the basic issue of the distinctness, on a world-wide scale, of boundaries between major units of geologic time. If it is possible that parts of the Cretaceous fauna survived a little longer in some areas than in others, or that important Tertiary elements appeared earlier in some areas (as has been suggested for *Truncorotalia* in the Tethys area by Bettenstaedt and Wicher, 1955, p. 515), the exact delineation of a world-wide datum plane marking the Cretaceous-Tertiary boundary on faunal evidence is likely to be unattainable.

### EOCENE

#### Mangaorapan stage

First appearance of *Globorotalia* (*Truncorotalia*) *crater* Finlay (*sensu stricto*), *Coleites* sp., and *Aragonia zelandica* Finlay. *Asterocyclina speighti* (Chapman) has been found only in Mangaorapan deposits at one locality. *Rzehakina* aff. *minima* Cushman and Renz is rare.

#### Heretaungan stage

*Elphidium hampdenensis* Finlay is restricted. First appearance of "*Globigerinella*" *iota* (Finlay), which is very close to "*Globigerinella*" *micra* (Cole). Last appearance of *Globorotalia* (*Truncorotalia*) *crater*. *Rzehakina* aff. *minima* is rare.

#### Porangan stage

*Elphidium saginatum* Finlay is restricted. *Truncorotalia* has not been found.

#### Bortonian stage

First appearance of *Globigerinoides index* Firsiay, *Hantkenina australis* Finlay, *Rotaliatina sulcigera* (Stache), of which *Rotaliatina mexicana* Cushman is probably a synonym, and *Sphaeroidina variabilis* Reuss. *Globorotalia centralis* Cushman and Bermudez is restricted. Only one or two doubtful occurrences of *Truncorotalia*. Highest occurrence of *Rzehakina* aff. *minima*.

#### Kaiatan stage

Discocyclinidae, *Hantkenina australis*, last *Sphaeroidina variabilis*. First *Amphistegina* and *Halkyardia*.

#### Runangan stage

Highest occurrence of Discocyclinidae, *Hantkenina australis*, *Coleites*, *Globigerinoides index*, and "*Globigerinella*" *iota* (Finlay), which is very close to "*Globigerinella*" *micra* (Cole). First appearance of *Sphaeroidina bulloides* d'Orbigny and *Bolivina* of the *Bolivina pontis-anastomosa* lineage. *Nummulitella polystylata* Dorreen is restricted.

Mangaorapan and Heretaungan microfaunas are very similar to the Lower Eocene Aragon microfaunas of Mexico (Nuttall, 1930), and are particularly characterised by abundant *Globorotalia* (*Truncorotalia*) *crater* Finlay, which is very close to and possi-



bly only a variant of *Globorotalia velascoensis* Cushman, which ranges from Paleocene to Lower Eocene according to Grimsdale (1951) and Hamilton (1953). The *Globorotalia crater* lineage appears first in the Waipawan, without the wide-open deep umbilicus that characterises *Globorotalia crater* sensu stricto in the Mangaorapan and Heretaungan. The form from the Lower Eocene of the Caucasus figured by Glaessner (1937a, pl. 1, fig. 6a-c) as *Globorotalia aragonensis* var. *caucasica* (= typical *Globorotalia velascoensis*, fide Grimsdale, 1951, p. 471) is closely similar to *Globorotalia crater*.

The appearance of "*Globigerinella*" *iota* (Finlay), which is probably a synonym of "*Globigerinella*" *micra* (Cole), in the Heretaungan coincides with the entry of this form elsewhere in the Lower Eocene (Grimsdale, 1951; Reiss, 1955). A very similar, slightly asymmetrical species in the Waipawan and Mangaorapan, described below as *Globigerina pseudoiota* Hornibrook, n. sp., is probably ancestral, the *micra* group having developed a symmetrical habit from an asymmetrical ancestor.

The foraminiferal fauna described by Todd and Kniker (1952) from the Agua Fresca shale in southern Chile bears a striking resemblance to the New Zealand Heretaungan, Porangan and Bortonian, and includes very close relatives of the highly characteristic species of *Elphidium* that are key species for the Heretaungan and Porangan. Todd and Kniker correlated these beds (over 6000 metres of fine silty clay) with the Upper Eocene Kreyenhagen shale of California, but the considerable thickness of fine-grained beds, and the resemblance to New Zealand Lower and Middle Eocene, suggest that the Agua Fresca shale is, in part at least, older than Upper Eocene.

Parangan faunas lack evidence of Lower Eocene elements and closely resemble Bortonian faunas, so the two are grouped together as Middle Eocene. The Bortonian is marked especially by the first appearance of *Globigerinoides index* Finlay, a member of a small group including *Globigerinoides mexicana* (Cole) and *Globigerinoides orbiformis* (Cole) which appears in the Middle Eocene in many parts of the world (Glaessner, 1937a, pl. 1, fig. 3, as *Globigerinoides conglobata* (Brady); Grimsdale, 1951; Reiss, 1952, p. 44; Reiss, 1955, p. 120).

*Hantkenina australis*, known from the Bortonian at a number of localities, belongs to the *alabamensis* group, which is more typical of the Upper than of the Middle Eocene. The Middle to Upper Eocene *Globorotalia centralis* also occurs sparingly in the Bortonian.

The absence of *Truncorotalia* from the Bortonian is puzzling, as *Truncorotalia aragonensis* is common in the Middle Eocene elsewhere (Grimsdale, 1951; Hamilton, 1953). Judging from the restricted *Truncorotalia* assemblage (only two or three species) and from the absence of *Hantkenina* below the Bortonian, New Zealand probably did not receive all the elements of the pelagic foraminiferal fauna that flourished throughout most of the world during the Paleocene and Eocene. A cool local climate during most of the Eocene has already been suggested (Hornibrook, 1953, p. 438) to explain the absence of Eocene larger foraminifera in New Zealand, and this may have prevented the spread of pelagic forms from the warmer Tethys area. Supporting evidence for a Lower to Middle Eocene (Ypresian-Lutetian) age for the Bortonian is provided by the presence together of the cephalopods *Aturia* (*Brazaturia*) and *Hercoglossa* (Fleming, 1945).

Kaiatan and Runangan microfaunas are very much alike except for a few species which first appear in the Runangan. Discocyclinidae, though rare, persist into the Runangan, together with *Globigerinoides index*, *Hantkenina australis*, *Coleites*, and "*Globigerinella*" *iota*, leaving little doubt that the Runangan is Upper Eocene. Very similar microfaunas with *Bolivina pontis* are found in southeastern Australia in the Brown's Creek beds and in South Australia in the "Transitional Marls" and Blanche Point marls (Reynolds, 1953) at Aldinga, and these beds must be close correlatives of the Runangan.

#### OLIGOCENE

##### Whaingaroan stage

Absence of Discocyclinidae, *Hantkenina*, *Coleites*, *Globigerinoides index*, and "*Globigerinella*" *iota*. Last appearance of *Rotaliatina sulcigera* in abundance, and of *Halkyardia*. First appearance of *Globigerina bulloides* d'Orbigny. No true *Globorotalia*.

##### Duntroonian stage

Rare *Rotaliatina sulcigera*, last ornamented *Vaginulinopsis*. No true *Globorotalia*.

##### Waitakian stage

First appearance of *Globoquadrina dehiscens* (Chapman, Parr and Collins) (= *Globoquadrina subdehiscens* Finlay). *Globigerina dissimilis* Cushman and Bermudez sensu stricto, and *Globigerina apertura* Cushman (rare). *Victoriella plecte* (Chapman), first appearance. No true *Globorotalia*.

##### Otaian stage

First appearance of *Ehrenbergina*, *Globigerina apertura* (in abundance), and *Nephrolepidina*, represented by *Nephrolepidina orakeiensis* (Karrer). *Victoriella plecte* is rare. No true *Globorotalia*.

In a number of sections, the Whaingaroan overlies the Runangan conformably, with transitional microfaunas between them. Since the Runangan is



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TABLE 2  
NEW ZEALAND RANGES OF SPECIES MENTIONED IN TEXT

	Mastrichian		Paleocene	EOCENE			OLIGOCENE			MIOCENE			PLIO-CENE		PLEISTOCENE		
	Haumuran	Teurian		L	M	U	L	M	U	L	M	U	L	U			
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undoubtedly Upper Eocene, a Lower Oligocene age for the Whaingaroan is very likely. The Duntroonian, with a microfauna hardly distinguishable from the Whaingaroan, also belongs to the Lower Oligocene, despite Kellog's conclusion (in Cloud, 1956, p. 570) that a Duntroonian whale of the genus *Kekenodon* indicates a Miocene age. In order to accommodate Kellog's Miocene determination, Cloud, in his correlation table, brings the Duntroonian up to the level where *Orbulina* enters. Such a correlation can only be made by ignoring New Zealand stratigraphy, since *Orbulina* does not appear there until very much later in the sequence. The persistence of *Rotaliatina* into the Whaingaroan and Duntroonian has a parallel in its occurrence in the Lower Oligocene Alazan formation of Mexico (Nuttall, 1932). Finlay (1946, p. 245) has already pointed out the resemblance between the microfaunas of the Oligocene lower Cipero formation of Trinidad and the Whaingaroan. In the absence of reticulate nummulites and other large foraminifera, there is little positive evidence for an Oligocene age other than the entry of *Nephrolepidina* in the Otaian. According to the range given by van der Vlerk (1955), *Nephrolepidina* could indicate a correlation with the Indonesian lower "e" stage, which is considered to be Chattian by Glaessner (1942). The occurrence of *Victoriella plecte* in the Waitakian and Otaian provides evidence for correlating these stages with the Australian Janjukian stage, for which this species is a key form according to Crespin (1950, p. 74).

#### OLIGOCENE-MIOCENE BOUNDARY

##### Hutchinsonian and Awamoan stages

The assemblages of these stages are very alike except for the following new entrants in the Awamoan: *Globorotalia miozea* Finlay (*menardii* type), which is rare, *Globigerinoides triloba* (Reuss), and *Globorotalia (Turborotalia)* n. sp. cf. *miocenica* Palmer.

##### Altonian stage

Appearance of common orbitoids, *Tryblilepidina* (rare), *Cyclocypeus*, *Eulepidina*, *Miogypsina intermedia* Drooger (restricted), *Globigerinoides bisperica* Todd, abundant *Globorotalia miozea*, and *Sphaeroidinella disjuncta* Finlay. Last appearance of *Globigerina dissimilis* (very rare).

##### Clifdenian stage

First appearance of *Orbulina suturalis* Bronniman and possibly *Orbulina univversa* d'Orbigny. *Tryblilepidina* and *Nephrolepidina* are not uncommon; occasional *Cyclocypeus* aff. *postidae* Tan (Finlay, 1947b).

##### Lillburnian stage

*Orbulina univversa* abundant. No orbitoids found. Appearance of *Uvigerina notohispida* (Finlay), which is close to *Uvigerina hispida* Schwager.

##### Waiauian stage

Last appearance of orbitoids, *Tryblilepidina*, *Cyclocypeus* aff. *indopacificus* var. *terhaari* Tan. *Sphaeroidinella seminula* (Schwager) appears.

The vexing question of the Oligocene-Miocene boundary, concerning whether it should be taken as the base or the top of the Aquitanian and the faunal criteria for separating the one period from the other, has occupied increasing attention during the past few years, and the problem has been discussed at length by Glaessner, Eames, Drooger, Stainforth, Kugler, Akers, Blow, and others. Because of widely divergent views, the correlation of Central American deposits with European stages is especially contentious, some authors regarding the *Globigerinatella insueta*, *Globorotalia fohsi* and *Orbulina* zones as Oligocene, others placing them as high as Helvetian-Tortonian. In New Zealand the Oligocene-Miocene problem can be attacked from two directions: (1) Correlation with Indonesia, especially by larger foraminifera, and (2) correlation, especially with Central America, by pelagic foraminifera. For the sake of maintaining uniformity with present usage in New Zealand, the Aquitanian is here taken as basal Miocene. As indicated by Glaessner (1953), a firm decision on this question is a matter for an International Geological Congress.

1) *Correlation of New Zealand with Indonesia*: Comparison of the ranges of New Zealand and Indonesian larger foraminifera is not entirely straightforward. Whereas Indonesia lay within the belt of tropical waters throughout the Tertiary and had a continuously evolving fauna of orbitoids and other larger foraminifera, New Zealand, which certainly had a cooler climate, was far removed from the centres of orbitoid evolution, and the few orbitoids that occur in the Middle Tertiary were undoubtedly invaders. The ranges of the larger foraminifera in Indonesia may not, therefore, apply very closely to New Zealand. In spite of the considerable difference of opinion concerning the ranges of many large foraminifera in Indonesia, there is general agreement that the last appearance of *Eulepidina* and the first appearance of *Miogypsina* characterise the upper "e" stage, which is regarded as Aquitanian by most workers. Finlay's (1947b, pp. 333, 334, 349) correlation of the Altonian, containing both of these forms, with the "e" stage is thus still valid. The final appearance of orbitoids (*Tryblilepidina*) in the Waiauian probably coincides with the last appearance of this group in the Indopacific in the upper "f" stage (or possibly a little higher; see Glaessner, 1953, p. 656). Finlay (1947b, pp. 334-335) discussed the

evidence provided by *Cycloclypeus* in the light of Tan Sin Hok's (1932) studies on this genus, and concluded that the Clifdenian form was close to *Cycloclypeus posteidae* Tan, a Burdigalian ("f" stage) species, whereas he found that the Waiuan species is almost identical with one of the forms of *Cycloclypeus indopacificus* var. *terhaari* Tan, a Vindobonian ("f" stage) species.

In view of van der Vlerk's opinion (1955) that correlation between the Tertiary "e" and "f" and the Chattian, Aquitanian, and Burdigalian (or Vindobonian) stages is at present not possible, it would seem that the best hope of correlation does not lie with the larger foraminifera, unless Drooger's studies of European and American Miogypsinae prove applicable to the Far East.

2) *Correlation by pelagic foraminifera*: Since the recognition of pelagic foraminifera as potential worldwide index fossils, much information on their Middle Tertiary ranges, especially in South America, has been published. Because the type sections of the Chattian, Aquitanian, Burdigalian and Helvetian contain very few planktonic species, lack of information on their ranges in the European Tertiary has retarded progress. Recent attempts by Akers (1955), Drooger (1956), and Akers and Drooger (1957) to correlate both pelagic and miogypsinid faunas on either side of the Atlantic have led to the conclusion that the Central American and Gulf Coast Middle Tertiary zones based on pelagics are considerably younger than previously thought, and that the incoming of *Orbulina* marks the Helvetian-Tortonian boundary. But Blow (1957) and Eames and Clarke (1957) have since pointed out that *Orbulina* occurs commonly in the Mediterranean Burdigalian, and they have reported several occurrences from high in the Aquitanian of the Mediterranean, East African and Australian regions.

Now that the evolutionary sequence *Globigerinoides triloba*—*Globigerinoides bispherica*—*Orbulina suturalis*—*Orbulina universa* is reasonably well established, not only in Central America (Blow, 1956) but also in the Mediterranean (Blow, 1957) and in New Zealand (Finlay, 1947b, pp. 339, 340), it is certain that *Orbulina* did not develop in a single area and later gradually spread around the world. Clearly, *Orbulina* and the group of *Globigerinoides* from which it was derived, like many other Middle Tertiary pelagic species, were very widely distributed. Such a rapidly evolving group, distributed over the greater part of the world, has a very high potential value for establishing a world-wide datum plane in the

Middle Tertiary. The importance of establishing the precise limits of the *Orbulina* zone in the Middle Tertiary of Europe does not have to be stressed.

If the appearance of *Orbulina* marks the upper Aquitanian, it supports the Aquitanian correlation of the Altonian indicated by *Eulepidina* and *Miogypsina*. No faunal criteria are yet known to establish the lower limit of the Aquitanian in New Zealand, and on the evidence available, the Hutchinsonian and Awamoan could be Upper Oligocene or Lower Miocene. The appearance of true *Globorotalia* (*menardii* type) in the Awamoan, after the complete absence of this genus since the Middle Eocene, is paralleled by the entry of *Globorotalia praemenardii* Cushman and Stainforth (1945) not far below *Orbulina* in the Trinidad Cipero marl (Zone II). This may be evidence of the Miocene age of the Awamoan. On the other hand, the invasion of warm-water forms with Indo-Pacific affinities during the highly transgressive Altonian stage marks the inception of a major local faunal episode corresponding more or less with the base of the Miocene.

#### UPPER MIOCENE AND PLIOCENE

##### Tongaporutuan stage

First appearance of *Bolivinita quadrilatera* (Schwager) and related species, *Rectobolivina striatula* Cushman, and rare *Uvigerina* aff. *pigma* (d'Orbigny). Highest common appearance of *Uvigerina notohispida* (Finlay) (aff. *hispida* Schwager) and many other Miocene species. *Globorotalia* aff. *menardii* d'Orbigny present.

##### Kapitean stage

First appearance of *Bulimina aculeata* d'Orbigny, *Streblus beccarii* (Linné), and *Patellinella inconspicua* (Brady). Last appearance of *Amphistegina*. Rare *Uvigerina notohispida*.

##### Opoitian stage

First appearance of *Globorotalia inflata* (d'Orbigny), *Globorotalia crassula* Cushman and Stewart, *Globorotalia truncatulinoides* d'Orbigny, *Globigerinoides rubra* (d'Orbigny), and *Globigerinella aequilateralis* (Brady). Highest *Sphaeroidinella seminula* (Schwager). A few lingering Miocene species. Common *Uvigerina* aff. *pigma*.

##### Waitotaran stage

A very few species persisting from the Miocene. First appearance of *Bulimina echinata* d'Orbigny and *Bulimina marginata* d'Orbigny.

Tongaporutuan microfaunas are very distinctly Miocene in character, including many of the species common in the earlier part of the Miocene. Finlay (1947b, pp. 345–347) has already pointed out the similarity between Tongaporutuan and Indo-Pacific Upper Miocene microfaunas, e.g., the upper Mena of New Guinea, the "g" stage of Indonesia, the Suva soapstone of Kar Nicobar, and also the Repetto

fauna of California. His suggestion that *Bolivinita* of the *quadrilatera* lineage is an important Upper Miocene marker must be modified in view of the statement of Kicinski and Belford (1956, pp. 72, 73) that *Bolivinita quadrilatera* occurs in the "f<sub>3</sub>" stage (Middle Miocene) in Papua.

The common Indo-Pacific Miocene species *Uvigerina hispida* Schwager, which is closely related to *Uvigerina notohispida* (Finlay) of the upper Southland and Taranaki series of New Zealand, was listed by Glaessner (1943, p. 69) among the important Indo-Pacific Miocene species that are never found in younger deposits. Finlay (1947b, p. 341) discussed the distribution of the *Uvigerina hispida* group (including *Uvigerina rustica* Cushman and Edwards), which is represented in Venezuela, Trinidad, California, Morocco, the Indo-Pacific and New Zealand in beds that are probably all Miocene.

In the late Tertiary, due primarily to the increasing trend toward biogeographic provincialism, which was probably accelerated by a cooling world climate, paleontological criteria for world-wide correlation are increasingly difficult to find. Foraminiferal evidence to define the Miocene-Pliocene boundary is not particularly clear-cut, and depends heavily on the extinction of many typical Miocene species before the beginning of the Pliocene. Once again, the pelagic species appear to hold the greatest hope for correlation, judging by the following report on Italian Pliocene pelagic foraminifera by di Napoli (1953, p. 14): "In the Pliocene, the planktonic assemblages assume a faunal composition similar to the present Mediterranean ones, with a large quantitative increase, chiefly in the Lower and Middle Pliocene, of *Globigerinoides sacculifer*, *Globigerinoides dubius* and *Globigerina inflata*. Various Globorotaliidae, previously absent, appear here (*Globorotalia crassula* and *Globorotalia hirsuta*), while the species that were present earlier disappear." Compare this with the statement by Finlay and Marwick (1940, p. 125) that the opoitian stage is characterised by the first appearance of "... the modern Globigerinidae including *Globigerinoides rubra* (d'Orbigny) and *sacculifera* (Brady), *Globorotalia inflata* (d'Orbigny), *crassula* Cushman and Stewart, and *truncatulinoidea* (d'Orbigny)."

Further direct evidence for correlating the Opoitian and Waitotaran with the Pliocene is provided by the occurrence of the pelagic mollusk *Hartungia postulata* (Bartrum), which has close relatives in the Pliocene of the Azores, Morocco and Australia (Fleming, 1953).

The earliest appearance of *Bulimina aculeata*, *Bulimina echinata*, *Bulimina marginata* and *Uvigerina pigmea* has been taken previously to support a Pliocene age for the Opoitian and Waitotaran (Finlay and Marwick, 1940, pp. 347-348), but both *Bulimina aculeata* and *Uvigerina pigmea* occur below the Opoitian, and all four species are recorded from the Upper Miocene of Italy (Cushman and Parker, 1947, pp. 115, 120, 121; Martinis, 1954, p. 136, table).

The warm climate that persisted during the Miocene in New Zealand was followed by continuous cooling in Opoitian and Waitotaran time, accompanied by the extinction of many species that had been established throughout much of the Middle Tertiary. Cooling of world climates during the Pliocene probably caused a slow contraction of the formerly wide belt of tropical water and its pelagic fauna, accompanied by advancing temperate and cool seas supporting a fast-developing pelagic fauna of their own. The dominance during the Opoitian and Waitotaran of *Globorotalia inflata*, *Globorotalia crassula*, and *Globigerina bulloides*, characteristic of temperate seas (Wiseman and Ovey, 1950), is very probably due to the post-Miocene northward advance of the temperate climatic belt. If the appearance of a large element of the modern planktonic fauna is closely bound up with the cooling sea, these species probably reached the equatorial belt a little later than they appeared in temperate latitudes, unless irregularities in the oceanic circulation carried them into low latitudes in some parts of the world. The possibility that Miocene pelagic (and benthonic) assemblages persisted a little longer in the equatorial belt than elsewhere cannot be ruled out.

#### PLIOCENE-PLEISTOCENE BOUNDARY

Except for a tendency toward small, restricted planktonic assemblages, little microfaunal evidence is at present known that would indicate a sudden cooling or marked climatic fluctuation in the upper part of the Wanganui series, although such evidence is available for the Mollusca (Fleming, 1944). Closer study of Nukumaruan and Castlecliffian microfaunas, and more information concerning the distribution of the Recent fauna, are essential to progress in solving this problem.

#### FOUR PROBABLE DATUM PLANES

In the foregoing account, the writer has necessarily had to deal with much conflicting and unsatisfactory evidence, so that correlation with overseas stages appears strong in some cases and weak in others. Four major faunal events stand out, however, as promising criteria from which to establish world-wide datum planes.



## NEW ZEALAND FORAMINIFERAL ZONES

1) Extinction of *Globotruncana*, followed by the appearance of *Globigerina* of the *triloculoides* type (Maestrichtian-Danian boundary).

2) Appearance of *Globorotalia* (*Truncorotalia*) (Upper Danian?, Paleocene?).

3) Extinction of *Hantkenina*, *Globigerinoides index*, "*Globigerinella*" *micra*, *Coleites*, and *Discocyclinidae* (Eocene-Oligocene boundary).

4) Appearance of *Orbulina suturalis* and *Orbulina univrsa* (upper Aquitanian-Burdigalian).

The extinction of *Lepidocyclina* sensu lato and *Mio-gypsina* approximately at the top of the "f" stage has long been known to mark an important time boundary in the Indo-Pacific.

In concluding this section, the writer wishes to acknowledge the debt that the present paper owes to the work of the late H. J. Finlay, whose paper "The foraminiferal evidence for Tertiary Trans-Tasman correlation," published in 1947, exhibits a masterly grasp of Tertiary microfaunas and literature far beyond the confines suggested by the title.

### NOTES ON SYSTEMATICS

Because of the inadequate illustrations of the pelagic foraminifera described by Finlay from New Zealand, and because of the scarcity of Finlay's papers, the present writer has illustrated a number of Finlay's types with camera-lucida drawings (plate 1). The types are deposited in the New Zealand Geological Survey collections, at Wellington.

#### *Globorotalia* (*Truncorotalia*) *crater* Finlay Plate 1, figures 3-5

*Globorotalia crater* FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, pt. 1, p. 125.

Not *Globorotalia crater* Finlay. - FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, pt. 3, pl. 29, figs. 157, 162, 163.

Finlay described this species as follows: "...like *aragonensis*... but has only four or five chambers per whorl, a sharp keel, and a practically flat top." No figure was given. The type locality is F5570, chalk marls below Amuri Stone, Hurunui River, one-half mile southwest of Trig. B (Lowry Peaks S. D.); Heretaungan stage (Lower Eocene).

The specimens later figured by Finlay as *Globorotalia crater* (F5671, S68/201, base of sandy marl separating greensands from the chalk marls, 30 chains northwest of the Middle Waipara gorge, left bank) are from older beds that are of Waipawan or Mangaorapan age (Paleocene-Lower Eocene), and are not typical. They

differ from *Globorotalia crater* sensu stricto in being smaller, without a wide-open umbilical depression, and in having a more prominent flange. *Globorotalia crater*, with its wide, deep umbilicus, squarish shape, and prominent ornamented dorsal sutures, is almost identical with the species figured as *Globorotalia velascoensis* Cushman by Hamilton (1953, pl. 30, figs. 16-18) from mid-Pacific seamounts.

#### *Globorotalia miozea* Finlay Plate 1, figures 6-10

*Globorotalia miozea* FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, pt. 3, pp. 326-327, pl. 29, figs. 159-161.

Finlay described this species as follows: "Of the *hirsuta* d'Orbigny type, variable in shape and thickness, both *menardii* and *tumida* forms occurring in all gradations; dorsally usually slightly convex, last chambers more flattened, about two coils with usually five chambers, sutures very convex, periphery increasingly lobulate with age, but not cordate; ventrally subconical at angle of about 140°, chamber bases narrowly swollen but not pointed, sometimes depressed; sutures deep, sinuous, no umbilicus, aperture sometimes narrow, usually fairly open with slight lip along outer side; whole shell densely perforate; dorsally smooth; ventrally with dense tiny pustules clustering around lower part of chambers decreasing in size with subsequent chambers, last two smooth; periphery sharp-angled to quite rounded; size 0.8 mm."

*Type locality*: F5089, Eason's Hill, Greymouth, New Zealand.

*Type level*: Middle part of Southland series, Middle Miocene.

At the type locality a minority of specimens have poorly developed final chambers, and Finlay selected one such specimen as the holotype (pl. 1, figs. 6-8). The large, broad final chamber more characteristic of *Globorotalia miozea* is better exemplified in the paratype illustrated in outline in pl. 1, figs. 9-10. *Globorotalia praemenardii*, described by Cushman and Stainforth (1945, p. 70, pl. 13, fig. 14a-c) from the Trinidad Cipero marl, Zones II and III, is very close to *Globorotalia miozea*, but is rather more compressed, with a sharper keel.

#### *Globigerina linaperta* Finlay Plate 1, figures 19-21

*Globigerina linaperta* FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, pt. 1, p. 125, pl. 23, figs. 54-57.

Finlay considered that *Globigerina linaperta* was easily distinguished from forms in higher horizons by "...a slight flattening and compression of each chamber and especially by its wide but very low and hardly open aperture directed laterally to overhang the previous chamber, instead of centrally, and with a pronounced rim." The pores are relatively large, their raised margins

forming a coarse reticulate pattern. *Globigerina linaperta* is related to *Globigerina triloculinoides* Plummer, which it very much resembles.

*Type locality*: F5179A, outcrop on beach 1 mile north of Kakaho Creek, Hampden section, South Island, New Zealand.

*Type level*: Bortonian stage, Middle Eocene.

*Remarks*: *Globigerina linaperta* has been reported from the Danian and Paleocene of Egypt (Nakkady, 1950; Said and Kenawy, 1956), and from the Eocene of mid-Pacific seamounts by Hamilton (1953, p. 222), who considered that "...the distribution now established for this form makes it an important world-wide index fossil."

#### ***Globigerina pseudoiota* Hornibrook**

Plate 1, figures 16-18

A minute, extremely finely perforate *Globigerina* characterised by an almost planispiral test consisting of one and one-half whorls of globular chambers, five or six in the last whorl. The aperture is simple, at the base of the final chamber, opening a little to one side of the plane of coiling.

*Type locality*: Holotype and thirty paratypes from locality F6045, Waipawa section, outcrop on roadside north of black siltstone, grid. ref. N 141/004847.

*Type level*: Waipawan stage, Paleocene.

*Dimensions of holotype*: Greatest diameter 0.28 mm.

*Remarks*: This tiny, almost planispiral *Globigerina* bears a striking resemblance to the small group of planispiral Eocene species of "*Globigerinella*" including "*Globigerinella*" *micra* (Cole) and "*Globigerinella*" *iota* (Finlay), and is probably an ancestor of "*Globigerinella*" *iota*, which replaces it in the Heretaungan.

#### **"*Globigerinella*" *iota* (Finlay)**

Plate 1, figures 22-24

*Nonion iota* FINLAY, 1940, Roy. Soc. New Zealand, Trans., vol. 69, pt. 4, p. 456, pl. 65, figs. 108-110.

*Globigerinella iota* (Finlay). - FINLAY AND MARWICK, 1947, New Zealand Jour. Sci. Technol., vol. 28, sec. B, pt. 4, p. 232.

Finlay described this species as follows: "Very similar to *Nonion micrum* Cole and *Nonion danvillense* Howe and Wallace... same small size and deep sutures as *danvillense*, but with the fewer chambers of *micrum*; more inflated chambers than either, leading to more lobulate periphery and more sunken umbilical area each side; shell usually more compressed with rounded periphery. Size 0.25 mm."

*Type locality*: F5300, Moeraki S. D., soft white marl at south end of beach (McKay's marly clay), South Island, New Zealand.

*Type level*: Bortonian stage, Middle Eocene.

#### ***Globigerinoides index* Finlay**

Plate 1, figures 11-14

*Globigerinoides index* FINLAY, 1939, Roy. Soc. New Zealand, Trans., vol. 69, pt. 1, p. 125, pl. 14, figs. 85-88.

Finlay described this species as follows: "From *conglobata* it is separable at sight in its fewer and regularly inflated, instead of flatly rounded, chambers and its totally different apertural system, each chamber having instead of the several tiny openings of *conglobata* one very large and widely gaping final opening and two others somewhat smaller above the sutures of previous chambers. The two species are similar in their deeply cleft sutures and robust shell walls." Finlay considered that *Globigerinoides orbiformis* (Cole) and *Globigerinoides mexicana* (Cushman) are more tightly coiled and have more chambers than *Globigerinoides index*. Two characteristics in particular distinguish *Globigerinoides index*, namely, the deeply incised sutures and the globular shape.

The diameter of the holotype is 0.44 mm., but in deeper-water faunas specimens up to 0.65 mm. in diameter are common.

*Type locality*: F5179A, outcrop on beach 1 mile north of Kakaho Creek, Hampden, South Island, New Zealand.

*Type level*: Bortonian stage, Middle Eocene.

*Remarks*: According to Grimsdale (1951), *Globigerinoides index* occurs in the Upper Eocene of Cuba, Trinidad and Syria. Reiss (1952, p. 45) records it from the Upper Eocene of Israel. It occurs also in the Upper Eocene in southeastern Australia.

#### ***Sphaeroidinella disjuncta* Finlay**

Plate 1, figure 15

*Sphaeroidinella disjuncta* FINLAY, 1940, Roy. Soc. New Zealand, Trans., vol. 69, pt. 4, p. 469, pl. 67, figs. 224-228.

Finlay described this species as follows: "Rather small, three or four chambers in ventral view, the fourth usually small, outline roughly triangular. Resembles *Globigerina triloba* but much more coarsely pitted, early chambers especially having numerous pustules; sutures deep, heavily channelled near umbilicus; aperture small, rounded, forming with umbilicus a deep cavity. A frequent tendency for last chamber to be smaller than others and somewhat jutting. Size 0.58 mm. In many respects halfway between *Globigerina* and *Sphaeroidinella*, lacking the polish, pore appearance and compactness of *dehiscens* but less like *Globigerina* in chamber attachment and deeply cleft sutures."

*Type locality*: F4270, Tangihanga, Waikohu S. D., Gisborne, North Island, New Zealand.

*Type level*: Altonian stage, Lower Miocene.

*Remarks*: *Sphaeroidinella disjuncta* is characterised by its coarsely porous surface with a distinct reticulate pattern and by its deeply channelled sutures. It appears to be closely related to *Sphaeroidinella rutschi* Cushman and Renz.

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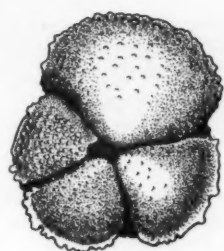
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## PLATE 1

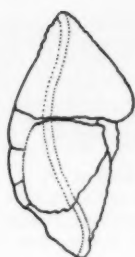
Numbers prefixed by "TF" refer to the New Zealand Geological Survey foraminiferal type collection.

- 1-2 *Globorotalia* aff. *crassata aequa* Cushman and Renz  
1, ventral aspect; 2, same specimen, edge view. Coll. F10,014, Te Uri Stream; Waipawan stage, Paleocene.
- 3-5 *Globorotalia* (*Truncorotalia*) *crater* Finlay  
Holotype, TF 1077/1. 3, ventral aspect; 4, edge view; 5, dorsal aspect.
- 6-10 *Globorotalia miozea* Finlay  
6-7, holotype, TF 1149/1: 6, ventral aspect; 7, edge view; 8, dorsal aspect. 9-10, paratype, TF 1149/4: 10, edge view.
- 11-14 *Globigerinoides index* Finlay  
11-13, holotype, TF 1076/1: 11, ventral aspect; 12, dorsal aspect; 13, side view. 14, paratype, TF 1076/2, ventral aspect.
- 15 *Sphaeroidinella disjuncta* Finlay  
Holotype, TF 1224/1, ventral aspect.
- 16-18 *Globigerina pseudoiota* Hornibrook, n. sp.  
16, paratype, TF 1324/2; 17-18, holotype, TF 1324/1.
- 19-21 *Globigerina linaperta* Finlay  
Holotype, TF 1078/1: 19, dorsal aspect; 20, side view; 21, ventral aspect.
- 22-24 "*Globigerinella*" *iota* (Finlay)  
22-23, holotype, TF 1182/1; 24, paratype, TF 1182/2.

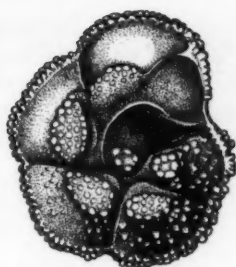




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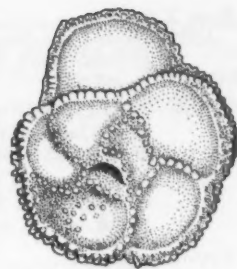
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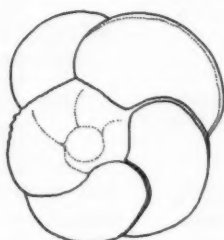
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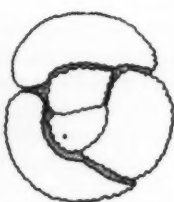
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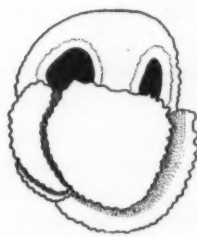
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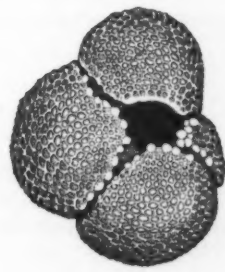
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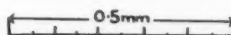
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**ABSTRACT:** *Megaspores referable to the European Lower Cretaceous species Pyrobolospora hexapartita (Dijkstra) and Minerisporites marginatus (Dijkstra) are recorded for the first time from Australian Upper Mesozoic deposits. Two new species of Pyrobolospora are described. A new "megaspore" genus, of which three species are distinguished, is instituted. The possible affinity of Pyrobolospora and of the closely associated microspore Perotrilites striatus sp. nov. with the Marsiliaceae is discussed. The stratigraphic position of the containing sediments is indicated.*

## Cretaceous "megaspores" and a closely associated microspore from the Australian region

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### INTRODUCTION

The work of Murray (1939), Dijkstra (1949, 1951, 1952), Hughes (1955), and others, showing that megaspore assemblages of the European Middle Jurassic, Wealden and Senonian deposits are individually distinct, clearly indicates that megaspores have a definite importance in Mesozoic stratigraphy. The occurrence herein reported of a small variety of large spores, some of which come into the size-range of megaspores (150 $\mu$  or more), in Australian Upper Mesozoic sediments is therefore of stratigraphic as well as palaeobotanical interest. Some of the types can be related closely to examples occurring in Lower Cretaceous beds in the Netherlands (Dijkstra, 1951) and England (Hughes, 1955), while others appear to be new types.

The age of the Australian "megaspore"-containing deposits is less certain than that of comparable sediments in Europe. Some have been referred to the Lower Cretaceous, others to the Jurassic period. This study indicates that all are Lower Cretaceous with the exception of the Nelson bore sediments, which are Upper Cretaceous. The deposits examined are fine grey to greyish-brown carbonaceous siltstones; a few contain macrofossils such as ammonites, gastropods, fresh-water pelecypods and plant remains, others only microspores, microplankton or both.

Unfortunately, these deposits are not as rich in megaspores as those of Europe and Great Britain, and consequently the method of recovery and mounting adopted by Dijkstra (1951) and Hughes (1955) was not followed. Instead, each rock was dissolved with hydrofluoric acid, and the residue, after several washings with distilled water, was passed through

a 100-mesh sieve. The material remaining on the sieve was then transferred to centrifuge tubes, and a mixture of concentrated nitric acid and a saturated solution of sodium chlorate added. After about twelve hours the residue was washed with water, then placed in a 50 per cent solution of glycerine and searched for megaspores. For the final mounting, glycerine jelly was used.

### LOCATION AND AGE OF SEDIMENTS

#### South Australia

(1) Near Robe, northern portion of section 714, Hundred of Waterhouse; South Australian Oil Wells no liability bore no. 1, at 1400 feet, 1780 feet, and 2630 feet; age "probably Jurassic" (Ward, 1917). (2) Loxton, near Renmark; Australian Oil and Gas Corporation Ltd. bore no. 1, at 1410-1415 feet; age Lower Cretaceous, probably Albion (see Stratigraphic Conclusions in the present paper). (3) Cootabarlow, near Lake Frome; bore no. 2, at 581 feet; age Lower Cretaceous, Albion (Cookson and Eisenack, 1957). (4) Tilcha, near Lake Frome; bore no. 2, at 460 feet and 1040 feet; age Lower Cretaceous, probably Albion. (5) Comaum bore, Hundred of Comaum, at 708 feet; age probably Lower Cretaceous (Cookson, 1954).

#### Victoria

(1) Victoria Department of Mines Dergholm bore no. 2, Parish of Dergholm, 16 miles east-northeast of Penola, South Australia, between 329 and 331 feet. (2) Barongarook Creek, southwest of Colac; age Lower Jurassic (Medwell, 1954). (3) Bellarine Peninsula, near Geelong, Little's shaft no. 2, between 38



TEXT-FIGURE 1

Map showing locations of deposits in which "mega-spores" have been found.

and 47 feet; age Lower Jurassic (Medwell, 1954).  
(4) Nelson, Parish of Glenelg; carbonaceous sediments from Victoria Department of Mines bore, between 6485 and 6487 feet; age Upper Cretaceous (Baker and Cookson, 1955).

#### New South Wales

Onepah Station near Tibooburra; soft, fine-grained sandstone from a well, at an unspecified depth; age Lower Cretaceous (H. O. Fletcher, in Deflandre and Cookson, 1955, p. 294).

#### Queensland

Styx River series, carbonaceous shale, from Queensland Geological Survey's bore no. 21 in the Tooloombah Creek area, at 327 feet; age Lower Cretaceous, Albion (Walkom, 1919).

#### New Guinea

Island Exploration Company's Omati bore, sample no. 2, Papua, New Guinea; age Lower Cretaceous, Albion (Cookson and Eisenack, 1957, text-fig. 2).

The geographic locations of all of these deposits are shown in text-figure 1.

#### SYSTEMATIC DESCRIPTIONS

Anteturma SPORITES H. Potonié, 1893

Turma TRILETES Reinsch, 1881

Subturma PYROBOLOTRILETES R. Potonié, 1956

Genus PYROBOLOSPORA Hughes, 1955

**Pyrobolospora hexapartita** (Dijkstra)

Plate 1, figure 1

*Triletes hexapartita* DIJKSTRA, 1951, Netherlands, Geol. Stichting, Meded., new ser., no. 5, p. 14, pl. 2, figs. 7-8.

*Pyrobolospora hexapartita* (Dijkstra).—HUGHES, 1955, Geol. Mag., vol. 92, pl. 10, figs. 4-5.

**Occurrence:** South Australia: Robe bore at 1400 feet and 1780 feet. New South Wales: Onepah Station well.

The ten specimens recovered from the above deposits are comparable with those obtained from Wealden deposits in England by Dijkstra (1951) and Hughes (1955). The spore consists of an approximately spheroidal body and a long neck composed of six leaf-like segments (pl. 1, fig. 1). The spore body is ornamented with a number of short cylindrical appendages which arise from the outer exoexine (the terminology followed is that of Hughes, 1955). This layer is relatively thick at the base of each appendage, but thins toward the distal extremity, which, in consequence, is frequently crumpled or destroyed. The surface of the spore body, neck segments, and appendages is finely granular; sometimes the appendages are dotted with larger granules.

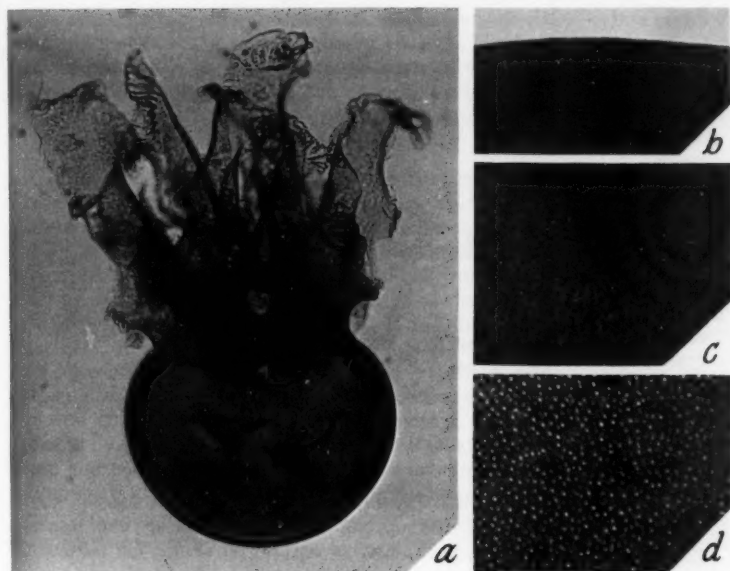
**Dimensions:** Equatorial diameter of spore body 154-275 $\mu$ ; total length including neck 308-450 $\mu$ ; appendages ca. 50 $\mu$  long.

**Pyrobolospora reticulata** Cookson and Dettmann,  
sp. nov.

Plate 1, figures 2-6

**Holotype:** National Museum of Victoria palaeontological collection, no. P 17502 (pl. 1, fig. 2).





TEXT-FIGURE 2

*Pyrobolospora nuda* Cookson and Dettmann, sp. nov., from the Tilcha bore, South Australia, at 460 feet: a, holotype, P 17522,  $\times 135$ ; b, optical section of exospore,  $\times 800$ ; c-d, surface view of exospore at high and low focus,  $\times 800$ .

**Occurrence:** South Australia: Robe bore at 1400 feet; Cootabarlow bore no. 2 at 581 feet; Loxton bore no. 1 at 1410 feet; and Tilcha bore at 1040 feet. Victoria: Bellarine Peninsula, Little's shaft no. 2, between 38 and 47 feet; and Dergholm bore no. 2, between 329 and 331 feet. New South Wales: Onepah Station well.

Megaspore consisting of an approximately spherical body with a reticulate surface and a long neck composed of six leaf-like segments which may be adherent along their margins or free along their entire length. Each neck segment is folded inward and supported by a median rib which arises from the exoexine and runs forward to taper off behind the apex. In some specimens the segments are finely and transversely plicate (pl. 1, fig. 4).

The exospore is about  $10\mu$  thick, and consists of three layers, an inner brown homogeneous intexine and a two-layered exoexine. The inner exoexine is about  $4\mu$  thick and dark brown in colour; the outer exoexine, which is more transparent, light yellow-brown, and about  $5\mu$  thick, is composed of radially arranged granules.

The surface reticulum is wide-meshed ( $20-30\mu$ ), and the lumina are polygonal or hexagonal in outline. The muri, about  $6-8\mu$  wide, are developed mainly from the exoexine, and are somewhat constricted at the angles. At these points the outer exoexine forms short funnel-shaped appendages homologous with those of *Pyrobolospira hexapartita*. The walls of the appendages thin distally, so that they are seldom found in a fully ex-

panded condition. The tetrad scar is relatively small (pl. 1, fig. 3), and is surrounded by the neck segments.

**Dimensions:** Equatorial diameter of spore body (twenty specimens measured)  $134-330\mu$ ; total length, including neck,  $285-550\mu$ ; length of neck  $132-250\mu$ .

**Comments:** *Pyrobolospira reticulata* is readily distinguishable from other species of *Pyrobolospira* by the clearly defined surface reticulum of the spore body. In this respect it comes nearest to *Pyrobolospira vectis* Hughes, from Wealden deposits in England, in which the spore body is covered with narrow ridges that "are arranged in a coarse reticulum of  $40-50\mu$  diameter or in a nearly regular spiral." However, a regular well-defined reticulum like that of *Pyrobolospira reticulata* does not appear to be present in *Pyrobolospira vectis*, and the appendages of this species are very much larger than those of *Pyrobolospira reticulata*.

***Pyrobolospira nuda* Cookson and Dettmann, sp. nov.**  
Text-figure 2

**Holotype:** National Museum of Victoria palaeontological collection, no. P 17522 (text-fig. 2a, c, d).

**Occurrence:** South Australia: Tilcha bore no. 1 at 460 feet.

The spore body is almost spherical (the proximal pole is compressed in the holotype) and without appendages. The six neck segments are strongly developed and are either joined or, as in the holotype, completely free from one another. In the three specimens recovered, the outer margins of the segments are plicate.

The exospore is yellow-brown, from 12–15 $\mu$  thick, and composed of four layers, a homogeneous intexine, in which a thin inner and a thicker outer intexine (ca. 3–4 $\mu$ ) can be distinguished, and a two-layered exoexine consisting of a granular inner exoexine about 5–6 $\mu$  thick and a finely pitted outer exoexine about 2–3 $\mu$  thick (text-fig. 2b).

**Dimensions:** Equatorial diameter of spore body 250–300 $\mu$ ; neck 308–396 $\mu$  long; total length 530–600 $\mu$ .

**Comments:** Of the seven species of *Pyrobolospora* that are now known from Lower Cretaceous deposits, *Pyrobolospora nuda* is the only one in which the exospore is devoid of appendages and has a pitted sculpture.

Subturma PYROBOLOTRILETES R. Potonié, 1956(?)

Genus *Balmeisporites* Cookson and Dettmann, gen. nov.

"Megaspore" consisting of a spherical body, 70–135 $\mu$  in equatorial diameter, with three equidistant reticulate equatorial outgrowths of the exoexine and a more prominent neck at the proximal pole composed of three united leaf-like segments, which surround the tetrad scar.

The generic name is given in honour of Mr. B. E. Balme, Geology Department, University of Western Australia.

Although the spores comprised by the genus *Balmeisporites* are well below the minimum size of most megaspores, they are tentatively associated with the subdivision Pyrobolotrilites because of certain morphologic features which they possess in common with the genus *Pyrobolospora* Hughes (1955). The neck-like structure that encloses the tetrad scar is similar both in position and in formation in the two genera, but in *Balmeisporites* it is composed of only three segments, whereas in *Pyrobolospora* it is composed of six.

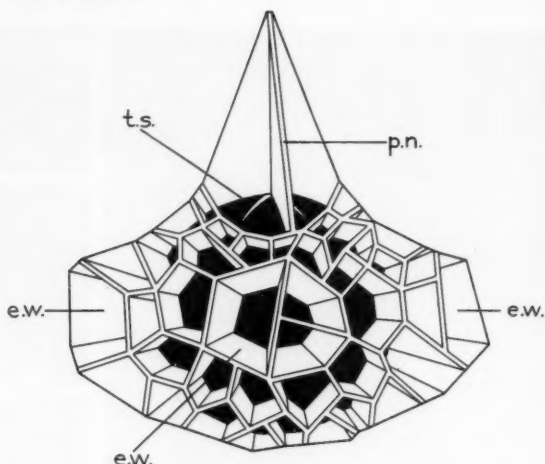
**Genotype:** *Balmeisporites holodictyus* Cookson and Dettmann, sp. nov.

*Balmeisporites holodictyus* Cookson and Dettmann, sp. nov.

Plate 2, figures 1–6; text-figure 3

**Holotype:** National Museum of Victoria palaeontological collection, no. P 17512 (pl. 2, fig. 1).

**Occurrence:** South Australia: Robe bore at 1400 feet, 1780 feet, and 2630 feet; Loxton bore no. 1 at 1410 feet; Cootabarlow bore no. 2 at 581 feet; and Tilcha bore no. 1 at 460 feet and 1040 feet. Victoria: Barongarook Creek, near Colac; and Bellarine Peninsula, near Geelong. New South Wales: Onepah Station well. Queensland: Styx River series bore no. 21 at 327 feet. New Guinea: Island Exploration Company's Omati bore no. 1, sample no. 2.



TEXT-FIGURE 3

*Balmeisporites holodictyus* Cookson and Dettmann, sp. nov. diagrammatic representation in equatorial view: p.n. = proximal neck; e.w. = equatorial wings; t.s. = tetrad scar. (Drawing by Dr. Suzanne L. Duigan.)

The spore body is roughly spherical, with an equatorial diameter of 70–120 $\mu$  and a coarsely reticulate surface; the neck is relatively short and usually does not exceed the diameter of the body. The total length of the body, including the neck, ranges from 160 to 180 $\mu$ .

The exospore is thin, and appears to be composed of only two layers, an inner brown homogeneous layer about 2–3 $\mu$  thick, and an outer thinner, finely granular layer that forms the surface reticulum and the segments of the neck. The muri of the reticulum are narrow, and the lumina, which are hexagonal or polygonal in outline, vary considerably in both width and depth according to their position on the spore body. They are widest and deepest at three equidistant areas around the equator, where they form more or less prominent wing-like outgrowths of equal or unequal height. The three neck segments situated around the proximal pole are usually united, but may be free (pl. 2, fig. 4). The are thin, flattened expansions with non-reticulate, granular surfaces. The tetrad scar is relatively large, the laesurae extending almost to the equator of the body. The surface of the exospore between the insertion of the neck segments and the scar is finely granular, and not reticulate as elsewhere.

*Balmeisporites tridictyus* Cookson and Dettmann, sp. nov.

Plate 2, figures 7–8

**Holotype:** National Museum of Victoria palaeontological collection, no. P 17518 (pl. 2, fig. 7).

**Occurrence:** South Australia: Robe bore at 1400 feet; and Tilcha bore no. 1 at 460 feet.

## AUSTRALIAN CRETACEOUS SPORES

The spore body is roughly spherical, with an equatorial diameter of 80–115 $\mu$  and a granular surface. The neck is approximately as long as the diameter of the body, the overall length, including the neck, being 170–190 $\mu$ . The three shorter equatorial outgrowths are coarsely reticulate, and vary from 40–80 $\mu$  in height.

The exospore is moderately thick, and consists of three layers, a homogeneous intexine about 1 $\mu$  thick, a dark brown, apparently homogeneous inner exoexine 3–4 $\mu$  thick, and a thin, granular, yellow-brown outer exoexine from which arise both the equatorial outgrowths and the segments of the neck. The muri of the equatorial outgrowths are rather stout and rigid, and the lumina are considerably deeper than broad (ca. 30–35 $\mu$  deep, 15 $\mu$  broad). The neck is composed of three non-reticulate, finely granular, leaf-like segments, which are placed symmetrically around the proximal pole and united by their margins to enclose the tetrad scar. A low and narrow thickening of the outer exoexine extends from each neck segment along the proximal surface of the body to merge with the reticulum of the corresponding equatorial outgrowths.

*Comments:* *Balmeisporites tridictus* differs from *Balmeisporites holodictus* in the absence of reticulate sculpturing on the proximal and distal surfaces, and in the thicker exospore.

***Balmeisporites glenelgensis* Cookson and Dettmann, sp. nov.**

Plate 2, figures 9–10

*Holotype:* National Museum of Victoria palaeontological collection, no. P 17520 (pl. 2, fig. 9).

*Occurrence:* Victoria: Nelson bore, Parish of Glenelg, between 6485 and 6487 feet.

Spore body circular in outline (all specimens have been considerably compressed), with an equatorial diameter of 107–135 $\mu$ . Exospore reticulate, about 5 $\mu$  thick, consisting of three layers, a highly refractive intexine about 1 $\mu$  thick, a brown, homogeneous inner exoexine about 4 $\mu$  thick, and a delicate, transparent, granular outer exoexine, which forms the reticulum. The meshes of the reticulum are numerous and vary considerably in width and depth, being smallest in both dimensions in the equatorial regions, between the wing-like projections. The three segments of the proximal neck are short in proportion to the size of the body and broadly attached. The tetrad scar is well defined.

*Comments:* *Balmeisporites glenelgensis* agrees with *Balmeisporites holodictus* in the complete development of the exospore reticulum, but differs in the larger size of the spore body, the thicker exospore, the shallower and closer mesh, and the finer muri. It approaches *Balmeisporites tridictus* in the size of the body and thickness of the exospore, but is readily distinguishable from this species by the more complete form of the exospore reticulum.

Turma ZONALES (Bennie and Kidston, 1886)  
R. Potonié, 1956

Subturma ZONOTRILETES Waltz, 1935

Infraturma ZONATI R. Potonié, 1956

Genus MINERISPORITES R. Potonié, 1956

***Minerisporites marginatus* (Dijkstra)**

Plate 1, figure 7

*Triletes marginatus* DIJKSTRA, 1951, Netherlands, Geol. Stichting, Meded., new ser., no. 5, p. 13, pl. 3, fig. 11.

*Baldurnisporites marginatus* (Dijkstra). – DELCOURT AND SPRUMONT, 1955, Soc. Belge Géol., Mém., new ser., no. 5, p. 73, pl. 4, fig. 5.

*Minerisporites marginatus* (Dijkstra). – POTONIÉ, 1956, Geol. Jahrb., vol. 23, p. 68.

*Occurrence:* South Australia: Robe bore at 1400 feet and 1780 feet; Loxton bore at 1410 feet; and Comaum bore at 708 feet. New South Wales: Onepah Station well. Victoria: Barongarook Creek, near Colac.

The megaspores referred to *Minerisporites marginatus* are rounded to subtriangular in polar view, and have a thin, finely granular flange, which is widest at the points of contact with the triradiate ridges. These ridges, which are undulate and considerably higher than wide, extend to the outer edge of the flange. The exospore is thin and irregularly reticulate, with rather wide lumina and narrow muri.

*Dimensions:* Overall equatorial diameter 275–392 $\mu$ ; equatorial flange about 16–45 $\mu$  wide.

*Comments:* The Australian megaspores recorded above have been referred to Potonié's genus *Minerisporites* rather than to his genus *Henrisporites* because of the clearly defined reticulate structure of the exospore. In *Henrisporites* (Potonié, 1956) the exospore is ornamented with small conical processes or spines, whereas in *Minerisporites* the exospore is described as reticulate. *Minerisporites marginatus* has previously been recorded from Lower Cretaceous (Wealden) sediments in the Netherlands (Dijkstra, 1951) and in Belgium (Delcourt and Sprumont, 1955).

Turma TRILETES Reinsch, 1881

Subturma AZONOTRILETES Lubert, 1935

Infraturma PERINOTRILITI Erdtman, 1947

Genus PEROTRILITES (Erdtman) ex Couper, 1953

***Perotrilites striatus* Cookson and Dettmann, sp. nov.**  
Plate 1, figures 8–12

*Holotype:* National Museum of Victoria palaeontological collection, no. P 17507 (pl. 1, figs. 8–9).

**Occurrence:** South Australia: Comaum bore no. 1 at 708 feet; Robe bore at 1400 feet, 1780 feet, and 2360 feet; Loxton bore no. 1, between 1410 and 1415 feet; Cootabarlow bore no. 2 at 581 feet; and Tilcha bore no. 1 at 460 feet and 1040 feet. Victoria: Barongarook Creek; Bellarine Peninsula; and Dergholm bore no. 2 at 329 feet. New South Wales: Onepah Station well. Queensland: Styx River series, Geol. Survey bore no. 21 at 327 feet. New Guinea: Omati bore, Papua, sample no. 2 (Cookson and Eisenack, 1957, text-fig. 2).

Microspores spherical to somewhat ellipsoidal, enclosed within a perispore; trilete, the laesurae slender, extending to the equator. Polar diameter 23–40 $\mu$ , equatorial diameter 32–42 $\mu$ , overall equatorial diameter, including the perispore, 35–54 $\mu$ .

Exospore about 2 $\mu$  thick, two-layered, brown. Perispore colourless, about 3 $\mu$  thick, reticuloid to rugulate, becoming more or less longitudinally striate toward the proximal surface, where it is detached from the exospore and forms a short neck-like projection.

PLATE 1

All photographs are from unretouched negatives. The letter "P" preceding a number indicates that the specimen has been deposited in the palaeontological collection of the National Museum of Victoria, Melbourne.

- 1 *Pyrobolospira hexapartita* (Dijkstra)  
P 17501,  $\times$  230. Robe bore, South Australia, at 1400 feet.
- 2–3 *Pyrobolospira reticulata* Cookson and Dettmann, sp. nov.  
2, holotype, P 17502,  $\times$  200, showing microspores of the *Perotrilites striatus* type amongst the neck segments;  
3, paratype, P 17503,  $\times$  275, showing open tetrad scar. Both from Robe bore, South Australia, at 1400 feet.
- 4 *Pyrobolospira reticulata* Cookson and Dettmann, sp. nov.  
Paratype, P 17504,  $\times$  100, showing plicate neck segments. Robe bore, South Australia, at 1400 feet.
- 5 *Pyrobolospira reticulata* Cookson and Dettmann, sp. nov.  
Optical section of exospore,  $\times$  ca. 200, showing appendages in side view. Dergholm bore, Victoria, between 329 and 331 feet.
- 6 *Pyrobolospira reticulata* Cookson and Dettmann, sp. nov.  
A fragment of an exospore,  $\times$  ca. 600, showing inflated ends of appendages. Robe bore, South Australia, at 1400 feet.
- 7 *Minerisporites marginatus* (Dijkstra)  
P 17506,  $\times$  200. Robe bore, South Australia, at 1400 feet.
- 8–9 *Perotrilites striatus* Cookson and Dettmann, sp. nov.  
Surface view and optical section of holotype, P 17507,  $\times$  ca. 600. Comaum bore, South Australia, at 708 feet.
- 10 *Perotrilites striatus* Cookson and Dettmann, sp. nov.  
P 17509,  $\times$  ca. 600. Styx River series, Queensland, bore no. 21, at 327 feet.
- 11 *Perotrilites striatus* Cookson and Dettmann, sp. nov.  
Proximal surface of a small specimen, P 17510,  $\times$  ca. 600. Robe bore, South Australia, at 1400 feet.
- 12 *Perotrilites striatus* Cookson and Dettmann, sp. nov.  
Paratype, P 17511, in profile,  $\times$  ca. 800, showing striated sculpture toward the proximal surface of perispore.
- 13–14 *Pilularia novae-hollandiae* A. Braun  
13, an acetolysed microspore,  $\times$  ca. 600; 14, portion of perispore of same specimen in surface view,  $\times$  ca. 600. Mooroopna, Victoria. National Herbarium of Victoria collection.





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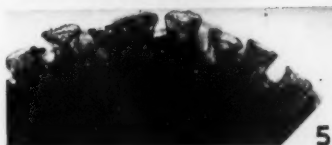
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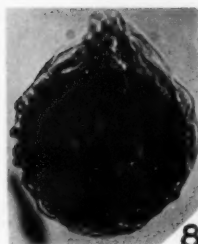
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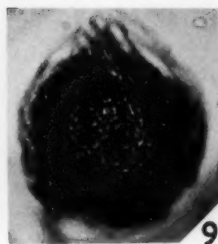
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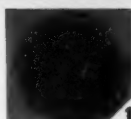
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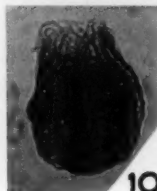
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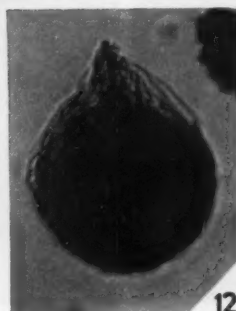
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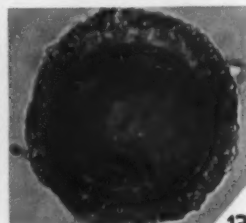
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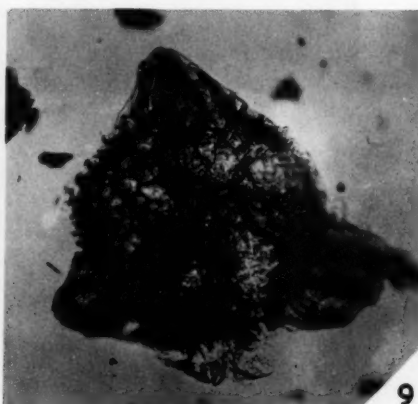
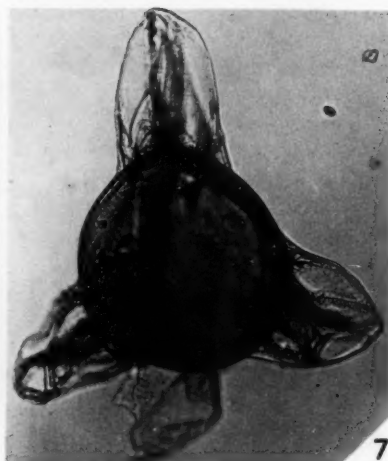
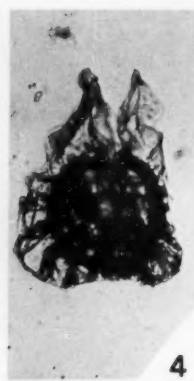
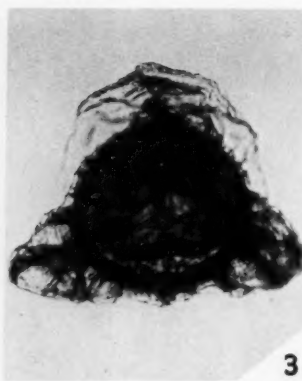
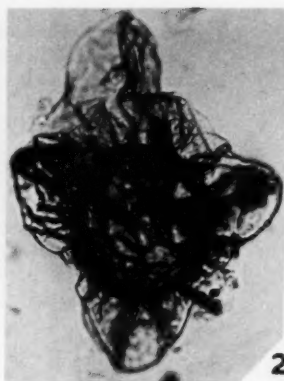
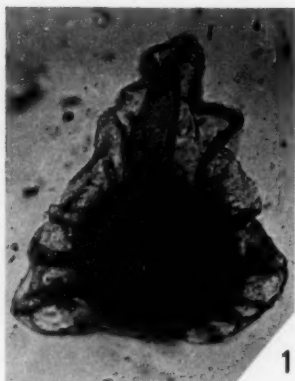
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14



Comments: *Perotrilites striatus* is morphologically similar to the microspores of *Pilularia novae-zealandiae* T. Kirk (Harris, 1955), *Pilularia novae-hollandiae* A. Braun, and *Regnellidium diphyllum* Lindley (Chrysler and Johnson, 1939). In these three species, as in *Perotrilites striatus*, a relatively thick perispore is developed, which is separated from the exospore above the tetrad scar, and the laesurae are slender and extend to the equator. *Perotrilites striatus* can be distinguished from the microspores of *Pilularia novae-zealandiae* and *Pilularia novae-hollandiae* by the somewhat more prominent neck and coarser sculpture of the perispore. Harris (1955) describes the sculpture of the microspores of *Pilularia novae-zealandiae* as "minutely rugulate," and a similar pattern occurs in *Pilularia novae-hollandiae* (pl. 1, fig. 14). The microspores of *Regnellidium* have not been available for comparison. It is clear, therefore, that *Perotrilites striatus* is referable to the Hydropterideae and bears a close affinity to the family Marsiliaceae. However, its generic position within this family is uncertain.

Two previous fossil records of hydropteridean microspores are of interest in this connection: (1) that of Sahni and Rao (1943), who closely compared microspores from the Lower Tertiary Intertrappean cherts of India

with those of *Regnellidium*, and (2) that of Couper (1953), who recorded microspores "identical in every respect" with those of *Pilularia novae-zealandiae* from the Ohika beds (Jurassic) of New Zealand.

#### POSSIBLE AFFINITY OF THE GENUS PYROBOLOSPORA

Very little is known regarding the origin of dispersed Cretaceous megaspores. Dijkstra (1951) has considered this question at some length, and has mentioned the Hydropterideae as a likely source of some of the types. Hughes (1955), in a special reference to the genus *Pyrobolospora*, wrote: "The elaborate and delicate appendages of *Pyrobolospora vectis* and *Pyrobolospora medusae* suggest aquatic habit." Although the present work can make no positive contribution to this question, some significance may be attached to the occurrence of the microspore *Perotrilites striatus* in all the deposits from which *Pyrobolospora reticulata* and *Pyrobolospora nuda* have been recovered, as well as amongst the segments of the megaspore necks themselves (pl. 1, fig. 2). The probable connection of *Perotrilites striatus* with the

#### PLATE 2

All photographs are from unretouched negatives. The letter "P" preceding a number indicates that the specimen has been deposited in the palaeontological collection of the National Museum of Victoria, Melbourne.

- 1 *Balmeisporites holodictyus* Cookson and Dettmann, sp. nov.  
Holotype, P 17512,  $\times$  ca. 270. Robe bore, South Australia, at 1400 feet.
- 2-4 *Balmeisporites holodictyus* Cookson and Dettmann, sp. nov.  
Paratypes: 2, P 17513,  $\times$  ca. 300; 3, P 17514,  $\times$  ca. 300; 4, P 17515,  $\times$  ca. 200. All from Robe bore, South Australia.
- 5 *Balmeisporites holodictyus* Cookson and Dettmann, sp. nov.  
Paratype, P 17516,  $\times$  350. Cootabarlow bore no. 2, South Australia, at 581 feet.
- 6 *Balmeisporites holodictyus* Cookson and Dettmann, sp. nov.  
P 17517,  $\times$  350. Robe bore, South Australia, at 1400 feet.
- 7 *Balmeisporites tridictyus* Cookson and Dettmann, sp. nov.  
Holotype, P 17518,  $\times$  315. Tilcha bore no. 1, South Australia, at 460 feet.
- 8 *Balmeisporites tridictyus* Cookson and Dettmann, sp. nov.  
Paratype, P 17519,  $\times$  ca. 350. Robe bore, South Australia, at 1400 feet.
- 9-10 *Balmeisporites glenelgensis* Cookson and Dettmann, sp. nov.  
9, holotype, P 17520,  $\times$  280; 10, paratype, P 17521,  $\times$  250. Both from Nelson bore, Victoria, between 6485 and 6487 feet.

TABLE 1

DISTRIBUTION OF "MEGASPORES" AND THE MICROSPORE *Perotrilites striatus*  
IN CRETACEOUS DEPOSITS OF THE AUSTRALIAN REGION

	Lower Cretaceous											Upper Cretaceous
	South Australia					Victoria			New South Wales	Queensland	New Guinea	Victoria
	Cootabarlow bore no. 2, 581 feet	Tilcha bore no. 1, 1040 feet	Loxton bore no. 1, 1410 feet	Comaum bore, 708 feet	Robe bore no. 1, 1400 feet	Barongarook Creek	Dergholm bore, 329-331 feet	Bellarine Peninsula	Onepah Station well	Styx River Series, bore no. 21, 327 feet	Omati bore, Papua, sample no. 2	Nelson bore, 6485 feet
<i>Pyrobolospira hexapartita</i>	—	—	—	—	+	—	—	—	+	—	—	—
<i>Pyrobolospira reticulata</i>	+	+	+	—	+	—	+	+	+	—	—	—
<i>Minerisporites marginatus</i>	—	—	+	+	+	+	+	—	+	—	—	—
<i>Balmeisporites holodictyus</i>	+	+	+	—	+	+	—	+	+	+	+	—
<i>Balmeisporites tridictyus</i>	—	+	—	—	+	—	—	—	—	—	—	—
<i>Balmeisporites glenelgensis</i>	—	—	—	—	—	—	—	—	—	—	—	+
<i>Perotrilites striatus</i>	+	+	+	+	+	+	+	+	+	+	+	—

Hydropterideae and in particular with the family Marsiliaceae has been mentioned above, but whether the close association of *Perotrilites striatus* with *Pyrobolospira reticulata* indicates a similar affinity for such megaspores or was purely accidental cannot be decided from the spores alone.

#### STRATIGRAPHIC CONCLUSIONS

The samples from which the "megaspores" and the microspore species *Perotrilites striatus* were recovered came from widely separated bore and outcrop successions (see text-fig. 1). The distribution of the species in the various samples is shown in Table 1. The deposits are of both paralic and lacustrine origin, and the ages previously ascribed to them range from Lower Jurassic to Upper Cretaceous.

The salt-water "megaspore"-containing deposits include those from Cootabarlow bore no. 2 at 581

feet, the nearby Tilcha no. 1 bore at 460 and 1040 feet, and the Loxton no. 1 bore at 1410 feet, all in South Australia; the Onepah Station well in north western New South Wales; bore no. 21 at 327 feet, in the Tooloombah Creek district of Queensland; and sample 2 of the Omati bore core in Papua, New Guinea (Cookson and Eisenack, 1957, text-figure 2). All of these sediments are of Lower Cretaceous (Albian) age. This opinion has been based chiefly upon the correlation between their contained microplankton and that of the Gearle siltstone of Rough Range, Western Australia (Cookson and Eisenack, 1957), the age of which has been determined on palaeontological grounds as Albian. It is also in agreement with the tentative correlation of the Cretaceous sediments below 1350 feet in the Loxton bore with the Tambo formation, of Albian age (N. H. Ludbrook, South Australia Department of Mines, Palaeontological Report no. 14/56, 1956, unpublished).



# AUSTRALIAN CRETACEOUS SPORES

The age of the fresh-water sediments has been estimated on less reliable data. Ward (1917) suggested that the sediments between 1400 feet and 4300 feet in the Robe bore, South Australia, are "probably Jurassic," and Cookson (1954), on palynological grounds, indicated a Cretaceous age for the sediments at 708 feet in the Comaum bore, South Australia. The deposits at Barongarook Creek and on the Bellarine Peninsula, Victoria, have both been referred by Medwell (1954) to the Lower Jurassic, on the basis of macroscopic plant remains. The age of the Dergholm bore sediments has not previously been determined.

The discovery, in these lacustrine sediments, of the megaspores *Minerisporites marginatus*, *Pyrobolospira hexapartita*, and *Pyrobolospira reticulata*, either singly or all three species together, has provided a hitherto unavailable means of correlation between European and Australian Upper Mesozoic deposits. The occurrence of *Minerisporites marginatus* and *Pyrobolospira hexapartita* establishes correlation with Wealden deposits of the Netherlands and with high Wealden or possibly Aptian deposits of England (N. F. Hughes, personal communication), and the presence of *Pyrobolospira reticulata* establishes correlation with the Australian Lower Cretaceous salt-water deposits mentioned above. A particularly strong link can be established between the Albian Onepah Station well sample and the Robe bore beds at 1400 feet. Both have yielded specimens of *Minerisporites marginatus*, *Pyrobolospira hexapartita*, and *Pyrobolospira reticulata*, thus providing good evidence in favour of an approximately contemporaneous Lower Cretaceous age. That all these megaspore-containing samples, except that from the Nelson bore, Victoria, are of approximately the same age (Lower Cretaceous, possibly Albian) is further indicated by the fact that all of them contain the "megaspore" *Balmeisporites holodictyus* and closely similar microfloras.

The sediments between 6485 and 6487 feet in the Nelson bore, Victoria, from which *Balmeisporites glenelgensis* was recovered, contain microspore and microplankton assemblages that are very similar to those occurring between 5782 and 6192 feet, which Baker and Cookson (1955) assigned to the Upper Cretaceous. A small variety of dicotyledonous pollen grains and the trilete spore *Mohriisporites australiensis* Cookson are present. *Mohriisporites australiensis* is well represented in all the Australian Lower Cretaceous megaspore-containing deposits, but angiosperm pollen grains have not been detected in these sediments.

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**ABSTRACT:** *The lamellar foraminifera, which construct their tests by the addition of lamellae of perforate calcite or aragonite, one per instar, covering the whole test, are here recognized as a distinct group and are separated from the non-lamellar foraminifera, which construct their tests by the simple addition, at each instar, of a chamber on the former apertural face. The lamellar group comprises part of the suborder Biloculinidea Sigal, and the superfamilies Lagenidea Glaessner, Buliminidea Glaessner, Rotaliidea Glaessner emend. Smout, Monolamellidea Reiss, and Bilamellidea Reiss. The present classification is based on anatomy, composition and texture of the chamber walls, apertural characters and tooth-plates, canal systems, and chamber arrangement. Although essentially not a phylogenetic ("vertical") one, the present classification supports Hofker's conclusions to a great extent. The families belonging to the various superfamilies of lamellar foraminifera are briefly discussed, and their systematic positions are indicated in tabular form. Photomicrographs of thin sections of various genera illustrate the important characteristics of the superfamilies.*

## Classification of lamellar foraminifera

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### INTRODUCTION

In the present paper an attempt is made to classify the foraminifera commonly known as "hyaline" or "calcareous-perforate," on the basis of the anatomy, composition and texture of the chamber walls, apertural characters and tooth-plates, canal systems, and chamber arrangement. This group of foraminifera constructs the chambers of the test by adding lamellae of aragonite or of granular or fibrous calcite, one per instar, covering the whole test. They are referred to herein as the "lamellar" foraminifera, as distinct from the "non-lamellar" ones, which build their test by the simple addition of a chamber on the previous apertural face at each instar, the wall of each chamber being confined, therefore, to the chamber it forms, without covering previously formed parts of the test. The classification proposed here supports many of the conclusions arrived at earlier by Glaessner, Smout, Hofker, Sigal, and others. On the other hand, it is shown here that many genera have been incorrectly interpreted by various authors, especially with regard to wall structure.

The present paper does not represent an exhaustive revision of the families involved; specimens of many important genera were not available to this writer, nor were topotypes of certain genotype species. The "orbitoidal" foraminifera will be discussed in a further paper. A part of the results of the present study is being published elsewhere (Reiss, 1957a).

The systematic positions of the families herein discussed are shown in Table 1. Photomicrographs of oriented thin sections illustrate the relevant characters of various genera discussed.

The writer feels greatly indebted to his assistant, Mrs. P. Merling, for preparing more than 350 oriented thin sections of foraminifera; to A. Zlatkine and Mrs. M. Pomerancblum of the Geological Survey of Israel for examining various specimens of foraminifera from a mineralogic-crystallographic point of view; to D. Blumenfeld for drawing the accompanying table; and to all of the many other persons who have put at the disposal of this writer valuable topotype material, without which this study would not have been possible.

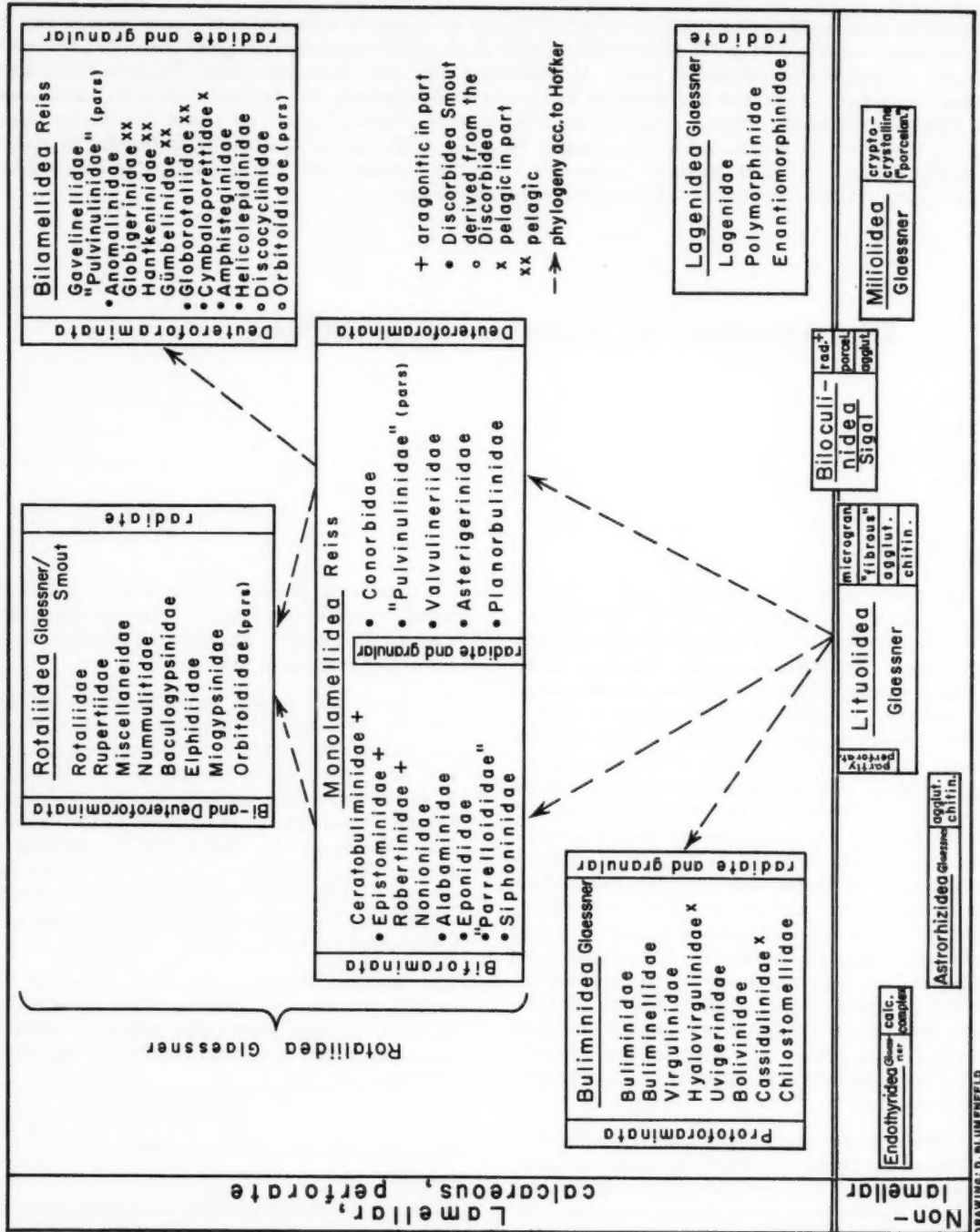
The oriented thin sections were prepared with canada balsam and carborundum powder. The photomicrographs were made with a "Praktiflex" camera mounted on a Reichert "Biozet" microscope with photo-oculars.

### WALL STRUCTURE OF LAMELLAR FORAMINIFERA

#### Anatomy

As stated above, the lamellar foraminifera construct their tests of lamellae of aragonite or calcite, one per instar, each lamella forming the wall of one chamber and at the same time covering the whole previously

TABLE 1  
CLASSIFICATION OF LAMELLAR FORAMINIFERA





## LAMELLAR FORAMINIFERA

formed test. The walls of previously formed parts of the test thereby become thickened and laminated; the thickened parts of the test are often referred to as the "supplemental" or "secondary skeleton," or as "secondary deposits." The lamellae are a secretion product of the protoplasm, and are deposited by a film of ectoplasm, apparently usually on a chitinous membrane or "lining." The morphogenesis of a lamellar test has been studied by Myers (1943), and its anatomy has been dealt with in detail by Smout (1954). The parting-lines between consecutive lamellae in the thickened portion of the test are usually more or less clearly visible in section, according to the state of preservation of the specimen and the mineralogical composition and texture of the wall material. As already shown by Smout (1954), the parting-lines are more clearly distinguishable in tests composed of fibrous ("radiate") calcite, especially if some solution has taken place at the tops of individual crystals. These parting-lines are extremely indistinct, however, in tests composed of granular calcite, and in any group may become obliterated by recrystallization. It is obvious that the septum of each chamber represents part of the corresponding lamella and is therefore single-layered. The same is true of the walls of the last-formed chamber.

Foraminifera that construct their tests according to this pattern are found in part of the Biloculinidea Sigal, and in the superfamilies Lagenidea Glaessner, Buliminidea Glaessner, and Monolamellidea Reiss (1957a). In the superfamily Rotaliidea Glaessner, as emended by Smout, an appendix to each individual lamella is formed in each chamber, on its inner side ("septal flap" of Smout, 1954), covering the distal face of the previous chamber and wedging out laterally, thus forming a double septum. This is the main character of the superfamily Rotaliidea as redefined by Smout. It must be emphasized that in this family the septa are "secondarily" doubled. As already pointed out by Smout (1954), it appears that the septal flap is actually part of a second layer, lining the roof of each chamber. The septal flap is obviously deposited concurrently with the main outer lamella and cannot, therefore, be deposited by the same ectoplasmic layer which deposited the latter. We must conclude that the septal flap is deposited by protoplasmic matter present on the inside (with respect to the chamber) of the main lamella.

In the superfamily Bilamellidea Reiss (1957a), the walls of each chamber, consist of two layers: The main outer lamella, which also covers the previously deposited parts of the test, and an inner lining, confined to each chamber and wedging out at the

margins of the previous septum and at the contact of the respective chamber with the previous coil. It is therefore present on the inside of each chamber on its distal face, on its "roof," and on its lateral chamber walls. It is obvious that in this case the septa are "primarily" double, as is also the distal or septal face of the last-formed chamber. The main outer lamella and the inner lining coalesce in the region of the aperture (peristomal area). These are the main characters of the superfamily Bilamellidea. Again it seems impossible for the internal lining to be deposited by the same protoplasmic layer as that which deposited (concurrently) the main outer lamella. The inner lining must be deposited by protoplasmic matter present on the inside of the chamber, i.e., of the outer lamella.

The part of the protoplasm that forms the septal flap in the Rotaliidea or the inner lining in the Bilamellidea is best referred to as "endoplasm." One phenomenon, however, needs further study and clarification, namely, the chitinous membrane bounding the main endoplasmic body in many (if not all) foraminifera (see Myers, 1943). Such a chitinous membrane has been found by this writer in many specimens of the Monolamellidea, Bilamellidea and Rotaliidea. As shown by Brotzen (1942), Hagn (1955), this writer (1957a), and others (see below), this membrane is always found in fossil specimens on the inside (with respect to the chamber) of the inner lining or of the septal flap. This would lead to the conclusion that a thin layer of protoplasmic matter present between the chitinous membrane and the ectoplasm is responsible for the deposition of the inner lining or of the septal flap. An alternative explanation would be that in the Rotaliidea and in the Bilamellidea two layers of ectoplasm deposit between them the two parts of the chamber wall over the chitinous membrane bounding the actual endoplasm. Protoplasmic matter is also present between the septal flap and the previous septum in the Rotaliidea, and between the inner lining and the main lamella in the Bilamellidea, as well as within the single-layered walls of some Rotaliidea; these parts of the protoplasm belong to "canal systems."

The main lamella of all lamellar foraminifera is at least partly pierced by pores, arranged in a regular pattern. The septal flap of the Rotaliidea is poreless. As pointed out above, however, it appears that the septal flap is actually part of a calcareous layer which also lines at least a part of the roof of each chamber; the latter part of the layer is perforate. The inner layer (lining) of the Bilamellidea is partly perforate and partly imperforate, according to the perforation

of adjacent parts of the main lamella. The latter is imperforate where it forms the apertural face. At least a part of each septum is therefore imperforate. Pillars, "ornamentation," and keels are always devoid of pores; some kinds of keels, however, contain what can be termed "canalicules" (see below). Scattered "pores" in the imperforate peristomal area represent apertures or canal exits. As shown by Smout (1954), pores become obliterated in the thickened parts of the test. Little is known concerning the function of true pores. Their presence or absence cannot be taken as the basis of major taxonomy. As shown by Hofker in various papers, however, their location, distribution, and size are important in classification and phylogenetic studies. The distinction between protopores and deuteropores seems to be essential in the classification of some families (e.g., the Globigerinidae).

All distinctly and regularly perforated foraminifera, regardless of pore size, have been shown during the present study to be lamellar, in support of Frizzell's statement (1949). Smout (1954, 1955, 1956) has stated that the Virguliniidae, Buliminidae, Ceratobuliminidae, Nonionidae, Gumbelinidae, Globigerinidae, and Cibicididae, as well as such genera as *Valvulinaria* and *Gyroidina*, do not show obvious thickening (lamination) of the test; all of these forms have been found during the present study to have distinctly lamellar tests (see also Reiss, 1957a). As already pointed out by Smout (1955), the "secondary skeleton" may be absent as a result of solution. The real structure of the test walls is often revealed only by carefully prepared thin sections of well preserved specimens.

#### Composition and texture

The foraminiferal test is composed of one of the following materials, or of a combination of them, either by layering or by mixture: Chitin; aragonite; calcite; or exogenous (adventitious) material, such as mineral grains or flakes, small bits of rock, or animal hard parts. Chitin forms the entire test of the "chitinous" foraminifera, the "basal lining" upon which adventitious material is cemented in some of the "agglutinating" foraminifera, and the membrane bounding the endoplasm below layers of aragonite or calcite in the "calcareous" foraminifera; it occurs mixed with calcite in the "porcellaneous" foraminifera. Aragonite forms the lamellae of certain "calcareous" foraminifera and part of the "cement" in some "agglutinating" species. Calcite forms the "cement" in most of the "Agglutinantia," the test of the "microgranular" or imperforate foraminifera, with or without adventitious material, and the test of all "calcareous perforate" foraminifera.

From the point of view of texture, aragonite occurs in the form of elongate crystals. Calcite occurs either in the form of spicules or granules, which may or may not be arranged according to a definite pattern and which range in size from about  $1.5\mu$  (crypto-crystalline) in the Porcellanea to  $10\mu$  as cement in the Agglutinantia, in the Microgranularia, and in the "granular-hyaline" perforate foraminifera; or as true fibers in the "radiate-hyaline" calcareous perforate genera. The so-called "fibrous" texture of the calcite in the fusulinids or paleotextulariids is actually a granular one, in which the granules are arranged in rows, mimicking "fibers" (Cummings, 1955, 1956). This structure might be referred to as "pseudofibrous." It is present in certain "microgranular" or "agglutinating" post-Paleozoic genera as well (e.g., *Marssonella*; see pl. 2, fig. 1). It always occurs in layers below "microgranular" or "agglutinating" layers. Optically, aragonite and calcite in true fibrous form show the features of the "radiate" group of Wood (1949). Siliceous tests may be of secondary origin, and will not be discussed here.

In most cases, neither composition nor texture can be taken as the only criterion in the classification of the foraminifera; in many cases, even a combination of both features is not sufficient. Pores have always been taken into account in characterizing the wall structure in the larger taxonomic units of the foraminifera. Layering and/or lamellar construction of the test walls is obviously a further important element. Clear distinction must also be made between adventitious material and secreted material (chitin, aragonite, or calcite). It follows that only "sets" of characters of the chamber wall constitute an adequate basis for classification.

The lamellar foraminifera are characterized by the following "sets" of characters:

- a) Aragonitic, "radiate," perforate; mostly, if not always, deposited on a chitinous membrane;
- b) Calcareous, fibrous, "radiate," perforate; chitinous membrane present, at least in some genera;
- c) Calcareous, granular, perforate; chitinous membrane often present.

A part of the superfamily Monolamellidea belongs to group a, the remainder to groups b and c. The Buliminidea and the Bilamellidea belong partly to group b and partly to group c. The Lagenidea and Rotaliidea belong exclusively to group b. Any attempt to classify the granular Buliminidea, Monolamellidea or Bilamellidea apart from the radiate forms belonging to these superfamilies fails to give logical results. Often a classification even

## LAMELLAR FORAMINIFERA

"cuts" through genera (see Wood, Smout, etc.). For these reasons, the lamellar granulate forms are not separated from the lamellar radiate forms, and the superfamilies Monolamellidea and Bilamellidea (Reiss, 1957a) are here formally emended so as to comprise both structural types.

As already pointed out by Smout (1956), the determination of the crystal structure is not easy in fresh material. Recrystallization of the aragonite or calcite in any group often results in fossil tests having granular structure, rendering the original structure a matter of interpretation (compare Smout, 1956; Reichel, 1956; and Reiss, 1957a). Some genera have been interpreted by certain authors as having a radiate structure and by others as having a granular one (see also below).

The distinction between "hyaline" and "opaque" walls made by Hofker in several of his papers, seems at best of specific value. Fossilization processes may change a "hyaline" wall to an "opaque" one or vice versa (compare also Reichel, 1956). "Hyaline" and "opaque" in Hofker's sense are not identical with radiate and granular, although sometimes Hofker seems to use them in this sense. Lamellar foraminifera are both "hyaline" and "opaque" in Hofker's sense.

### Ornamentation

Ornamentation is an integral part of the test wall, and will be discussed briefly here. What has been said by Smout (1954) with regard to pillars especially textural and inflational ones) applies to the ornamentation and to most types of keels in all lamellar foraminifera. Papillae, spines, striae, costae, costellae, etc., are essentially of the inflational type. Keels are mostly of inflational type, but some are of textural type, and some have been regarded as being formed by the tooth-plate (e.g., *Laticarinina*). Keels and pillars are apparently formed at weak points in the chamber wall, such as places where the lamella bends sharply. Some keels (Globorotaliidae) are formed by the outward bending of the main lamella, and are apparently formed in connection with the canal system; they are present not only on sharply angled parts of the test, but also on completely rounded ones (see Reiss, 1957a). Inflational and textural ornamentation is invariably imperforate. So are keels, but some of them are pierced by tubular canals (Nummulitidae) or by scattered canalicules (Bilamellidea, e.g., Globorotaliidae). Continuity of ornamentation over suture lines, and accentuation of ornamental features, including thickening of keels, on ontogenetically earlier chambers in lamellar foraminifera, are easily explained by the lamellar structure as such, or superposition.

### CANAL SYSTEMS

Canal systems are found in two superfamilies of the lamellar foraminifera, the Rotaliidea and the Bilamellidea. The canal systems of the Rotaliidea have been dealt with in detail by Smout (1954). Those of the Bilamellidea have been regarded by many authors as doubtful. The canal systems of the Amphisteginidae, Discocyclinidae and various orbitoids have been a familiar subject of discussion for many years. The "dark lines" in these forms, as well as in various anomalinids and globorotaliids, have been variously interpreted (see Barker and Grimsdale, 1936; Bronnimann and Brown, 1956; Hofker, op. div.; Reichel, 1950; Schweighauser, 1953; Reiss, 1957a; and others). Some authors have interpreted the dark lines as canals, others as simple "parting-lines" between layers of the wall. Bronnimann and Brown (1956) assume that the dark lines in the septa of the Globotruncaninae represent the place of a chitinous membrane, on both sides of which the double septa have been deposited. The dark lines and points seen in section in the keels of the Globotruncaninae are not regarded by the latter authors as canals in section.

This writer's observations can be summarized as follows: The dark lines produced at the contact surfaces of consecutive main lamellae in thickened parts of the test cannot be compared with the dark lines between the outer or main lamella and the inner lining in the Bilamellidea. The latter type of dark lines are usually clearly visible, even when the parting-lines between consecutive main lamellae are obliterated and indiscernible, and they are also much broader than the parting-lines of the laminated, thickened parts of the test. They invariably expand toward the apertural area into a broadened peristomal space, which communicates both with the outside and with the inside of the chamber through scattered "pores" (see Reichel, 1950). This writer does not believe that these spaces (for such they obviously are), represented in section by dark lines expanding into rounded "dots" near the aperture, were originally hollow. It is likewise not believed that they represent the place of a former chitinous membrane, especially since this would lead us to the conclusion that two such membranes are present in each chamber of bilamellid tests. Furthermore, if puckering of the assumed second, and outer, membrane is responsible for the formation of the "canaliculate" keels of the Globotruncaninae (Reiss, 1957a), as assumed by Bronnimann and Brown (1956), it is difficult to explain the cause of such "puckering," or the presence of "pores" leading from and to the presumed membrane through the test walls.



It appears that the spaces between the main lamella and the inner lining in the Bilamellidea were originally filled by protoplasmic matter, which communicated with the main protoplasmic body both on the outside and in the interior of the chamber through canalicules. The latter are found mainly in the peristomal area and in the keels of the Globorotaliidae. The spaces between the main lamella and the inner lining actually occur *within* the walls of individual chambers, and may properly be referred to as "canal systems." The interlamellar "dark lines" between consecutive main lamellae in thickened parts of the test represent contact surfaces.

#### APERTURAL CHARACTERS

As far as the apertural characters of the lamellar foraminifera are concerned, the reader is referred to the descriptions given by various authors, especially Glaessner, Hofker, and Smout. The lamellar biloculinids, the Lagenidea, the Buliminidea, the Monolamellidea, and the Bilamellidea have primarily-formed apertures. The Rotaliidea have "no aperture, or pores on the apertural face, or pores elsewhere, sometimes with interiomarginal intercameral foramina, or showing derivation from such a form" (Smout, 1955). Accessory apertures are primarily-formed, in the sutural position, in some Monolamellidea and Bilamellidea, and "stolons" are found in members of these superfamilies, as well as in the Rotaliidea. Labial apertures, formed by apertural lips, are found in some Bilamellidea (Reiss, 1957a). Such are the so-called "accessory" or "intra-umbilical apertures" of the Globotruncaninae.

With regard to Hofker's classification of the "Dentata," this writer accepts Smout's (1956) suggestion that the Rotaliidea should be regarded as a distinct group, regardless of whether they are Biforaminata or Deuteroforaminata in the sense of Hofker, and that the "complex" Peneroplidae should be removed from the Dentata of Hofker. Glaessner's (1954) suggestion that the "dentate" Valvulinidae need further study with regard to their relationship to various other groups of foraminifera is emphasized, and his alternative explanation that the presumably biforaminine *Cibicides* has a deutero-foramen is accepted and supported by other findings (see below).

It can be seen from Table 1 that a) all Buliminidea are protoforaminine in the sense of Hofker (see also Glaessner, 1954); b) the Monolamellidea are mostly biforaminine and partly deuteroforaminine; c) the deuteroforaminine Monolamellidea are apparently

ancestral to the Bilamellidea (compare Brotzen, Glaessner, Hofker, Smout, and others); and d) the Bilamellidea are all deuteroforaminine. The lamellar Biloculinidea and the Lagenidea are "non-dentate." According to Hofker, the families here placed (in agreement with Smout) in the Rotaliidea have arisen from families which belong both to biforaminine and deuteroforaminine Monolamellidea. The present study supports the basic importance of Hofker's concept of the "tooth-plate foraminifera."

#### CHAMBER ARRANGEMENT

All lamellar foraminifera are pluriloculine except for certain forms usually regarded as belonging to the Biloculinidea. The latter (such as *Trocholina*) are, however, better referred to as "protoseptate" pluriloculinids because they show constrictions, each corresponding to a primitive septum and indicating a growth episode. The Buliminidea have a chamber arrangement which is essentially trochospiral, mostly high-spired. Biserial and uniserial forms of this group are derived from a trochospiral arrangement. The Monolamellidea, Bilamellidea and Rotaliidea are trochospiral, usually low-spired, or planispiral. Biserial and uniserial forms among the Bilamellidea must be regarded as derived from a trochospiral arrangement. The Lagenidea are planispiral, trochospiral, biserial (both true and derived from a trochospiral arrangement), or (in most Lagenidae and in some Polymorphinidae and Enantiomorphinidae) uniserial. The lamellar Biloculinidea, so far as known, are trochospiral. Orbital chambers are found in the Bilamellidea and in the Rotaliidea.

#### ECOLOGY

The lamellar foraminifera are mostly benthonic. However, all known planktonic foraminifera are also lamellar. The greatest number of the pelagic genera belong to the Bilamellidea, but some of them are found in the Buliminidea. The position of *Tretomphalus* has not been studied by this writer; if it is a monolamellid, it is the only one known to be planktonic.

#### THE FAMILIES OF THE LAMELLAR FORAMINIFERA

There follow some brief remarks concerning the various families of the lamellar foraminifera. As far as the Lagenidea are concerned, Glaessner's and Sigal's classifications are followed; as far as the Rotaliidea are concerned, Smout's classification is followed. Hofker's families are used for the classification of the Buliminidea, Monolamellidea and Bilamellidea. Some of Hofker's families, however, are invalid for



## LAMELLAR FORAMINIFERA

formal nomenclatural reasons, others are based on incorrectly observed characters, and a few are apparently meaningless heterogeneous groups. Some need further study. As pointed out above, the present classification is not a phylogenetic or "vertical" one like that of Hofker (see Glaessner, 1954), but a "horizontal" one; Hofker's orders and suborders cannot, therefore, be considered here as such.

It has already been stated above that specimens of various important genera either were not available to this writer or were not suitable for detailed study. This is true of *Laticarinina*, *Tretomphalus*, the Chapmanininae in the sense of Frizzell (1949), and others. Hofker (1956c) places *Ferayina* in the Valvulinidae. In the present writer's opinion, this conclusion needs further study, especially since *Ferayina* is distinctly lamellar. *Chapmanina* has two-layered walls. No material belonging to these genera was available to the present writer.

### Order FORAMINIFERA

#### Suborder BILOCULINIDEA Sigal

##### Family Spirillinidae (?)

The genera *Spirillina*, *Conicospirillina*, *Trocholina* (aragonitic; see Reichel, 1956), and *Neotrocholina* are lamellar. *Paalzowella* and *Vidalina* probably also belong here. The whole group of the so-called Biloculinidea needs detailed revision.

#### Suborder PLURILOCULINIDEA Sigal

##### Superfamily Lagenidea Glaessner

###### Plate 1, figures 1-2

The characters of this superfamily have been discussed above. It comprises three families, the Lagenidae, Polymorphinidae, and Enantiomorphinidae. Nothing essentially important can be added to what is known of the genera belonging to these families.

##### Superfamily Buliminidea Glaessner

###### Plate 2, figures 2-6

The main characters of this superfamily have been discussed above; all of its members are lamellar (but see Smout, 1956). This superfamily represents essentially the "ordo" Protoforaminata Hofker (see Glaessner, 1954). The family Ellipsoidinidae, often included in this superfamily, needs further study. It may be polyphyletic, and is not discussed here.

##### Family Buliminidae

According to Hofker, this family includes only the genus *Bulimina*. It has radiate wall structure.

##### Family Buliminellidae

The genera *Buliminella*, *Buliminellita*, *Buliminoides*, and *Praebulimina* are included here. Wall structure radiate (see Haynes, 1954; Wood, 1949). Hofker has stated that *Praebulimina* shows an opaque wall structure like that of *Allomorphina*; the latter, however, is granular.

##### Family Virgulinidae

Hofker includes this group in the Cassidulinidae. In this writer's opinion, it seems appropriate to separate the two groups. *Virgulina* and *Virgulinella* seem to belong to the Virgulinidae. Both genera have granular wall structure. According to Hofker, the genus *Candeina* (with radiate structure) is derived from *Virgulinella*. It is here placed in the Cassidulinidae.

##### Family Hyalovirgulinidae

The reason for erecting this family was not given by Hofker and is not clear. The family Hyalovirgulinidae is practically identical with the family Globobuliminidae Hofker, with the addition of a few genera. The following genera are included here: *Stainforthia*, *Virgulinopsis*, *Bitubulogenerina*, *Reussella*, *Praeglobobulimina*, *Protoglobobulimina*, and *Globobulimina*. All of them have radiate wall structure (see Wood, 1949; Haynes, 1954; and Hofker, op. div.). *Stainforthia* is apparently pelagic, and the *Globobulimina* group is regarded by Hofker as being pelagic.

##### Family Uvigerinidae

This family includes the genera *Uvigerina*, *Angulogerina*, *Praeuuigerina*, *Eouuigerina*, *Pseudouuigerina*, *Trifarina*, *Hopkinsina*, *Siphogenerina*, and *Siphogenerinoides*. All seem to have radiate walls.

##### Family Bolivinidae

The genera *Bolivina*, *Bolivinoidea*, *Loxostomum*, *Rectobolivina*, and *Bifarina* belong here. Hofker (1956d) believes that some of these genera represent subgenera of or are identical with *Bolivina*. The position of *Bolivinita*, *Tappanina*, and *Trachelinella* is uncertain.

##### Family Cassidulinidae

The genera *Virgulina* (= *Cassidella*) and *Virgulinella* have here been removed for the time being from the Cassidulinidae, although Hofker includes them in this family. The family Cassidulinidae seems to include the genera *Cassidulina*, *Cassidulinoides*, *Ehrenbergina*, and *Sphaeroidina*, as well as *Candeina*, *Globigerinatella*, *Pleurostomella*, and *Pleurostomellina*. The position of the four last-mentioned genera needs further study, although their grouping in this family seems correct. *Cassidulinoides*, *Sphaeroidina*, *Candeina*, and *Globigerinatella* have radiate structure. Some species of *Cassidulina* and *Ehrenbergina* have radiate structure, and others have granular structure. *Pleurostomella* and *Pleurostomellina* are granular (see Wood, 1949). *Candeina* and *Globigerinatella* are pelagic in habitat.

Family **Chilostomellidae**

The genera *Chilostomella*, *Chilostomelloides*, *Allomorphina*, *Quadriformina* and *Rotamorphina* belong here, and apparently also *Pullenia*. All have granular wall structure.

Superfamily **Monolamellidea** Reiss

Plate 1, figures 3-4; plate 2, figures 7-22; plate 3, figures 1-10

This superfamily has been erected (Reiss, 1957a) for a part of the superfamily Discorbidea Smout (1954). It is here formally emended to include both radiate and granular genera.

## A. BIFORAMINATE FAMILIES:

Family **Ceratobuliminidae**

The genera of this family have been discussed in detail by various authors (see especially Troelsen, 1954, and Hofker, op. div.). It seems to include the genera *Ceratobulimina* (with the subgenera *Ceratolamarckina*, *Ceratocancris*, and *Ceratobulimina* s. str.) and *Lamarckina*. They have aragonitic tests and radiate structure. They are distinctly lamellar (but compare Smout, 1956).

*Begia* Smout, a synonym of *Nezzazata* Omara, is non-lamellar and has granular, apparently imperforate walls. It cannot be included in the Ceratobuliminidae, as proposed by Smout (1956). *Nezzazata* has been discussed elsewhere (Reiss, 1957b).

Family **Epistominidae**

This family comprises the genera *Epistomina*, *Epistominoides*, *Voorthuysenia*, *Höglundina*, *Hiltermannia*, and *Brotzenia* (= family Epistomariidae Hofker). All have apparently aragonitic tests and radiate wall structure (Bandy, 1954; Todd and Blackmon, 1956; Troelsen, 1954; Wood, 1949). *Epistominella* has calcareous radiate walls and probably belongs to the Eponididae.

Family **Robertinidae**

The genera *Robertina*, *Robertinoides*, *Pseudobulimina*, *Cushmanella* and *Colomia* belong here. All have radiate walls. *Colomia* is aragonitic (Bandy, 1954). A sort of "canal system" is described by Hofker in *Cushmanella*; it is formed by the tooth-plates. This aberrant genus needs further study.

## PLATE 1

In the schematic drawings, o.l. = outer lamella; i.l. = inner lining; s.f. = septal flap; c. = canals.

## a Schematic drawing of a lagenid in equatorial section.

1 *Robulus* sp.

Horizontal section,  $\times 55$ . IT 73; Midway, Texas.

2 *Robulus* sp.

Vertical section,  $\times 55$ . IT 74; Midway, Texas.

## b Schematic drawing of a monolamellid in equatorial section.

3 *Alabamina wilcoxensis* Toulmin

Horizontal section,  $\times 55$ . IT 72; Lower Eocene, Israel.

4 *Valvulineria californica* Cushman

Vertical section,  $\times 55$ . IT 47; Miocene, California.

## c Schematic drawing of a bilamellid in equatorial section.

5 *Pseudovalvulineria lorneiana* (d'Orbigny)

Horizontal section,  $\times 100$ . IT 3; Campanian, Paris Basin.

6 *Planulina ariminensis* (d'Orbigny)

Vertical section,  $\times 82$ . IT 89; Pliocene, Israel.

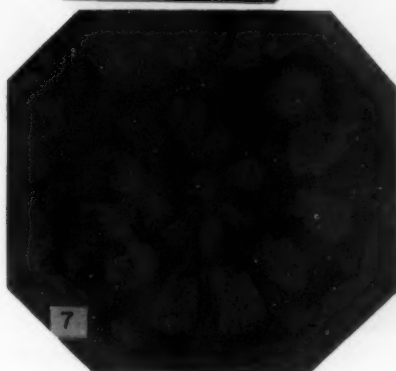
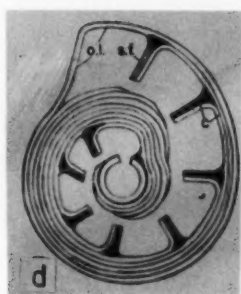
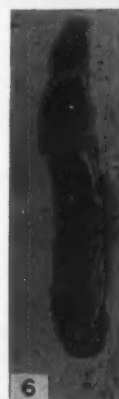
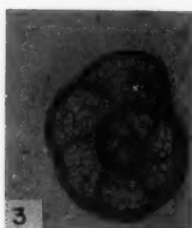
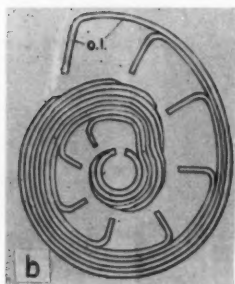
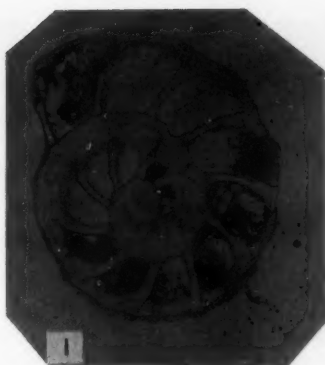
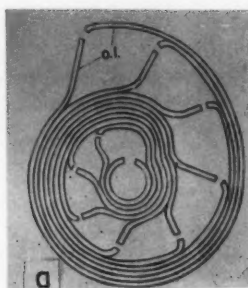
## d Schematic drawing of a rothliid in equatorial section (modified after Smout, 1954).

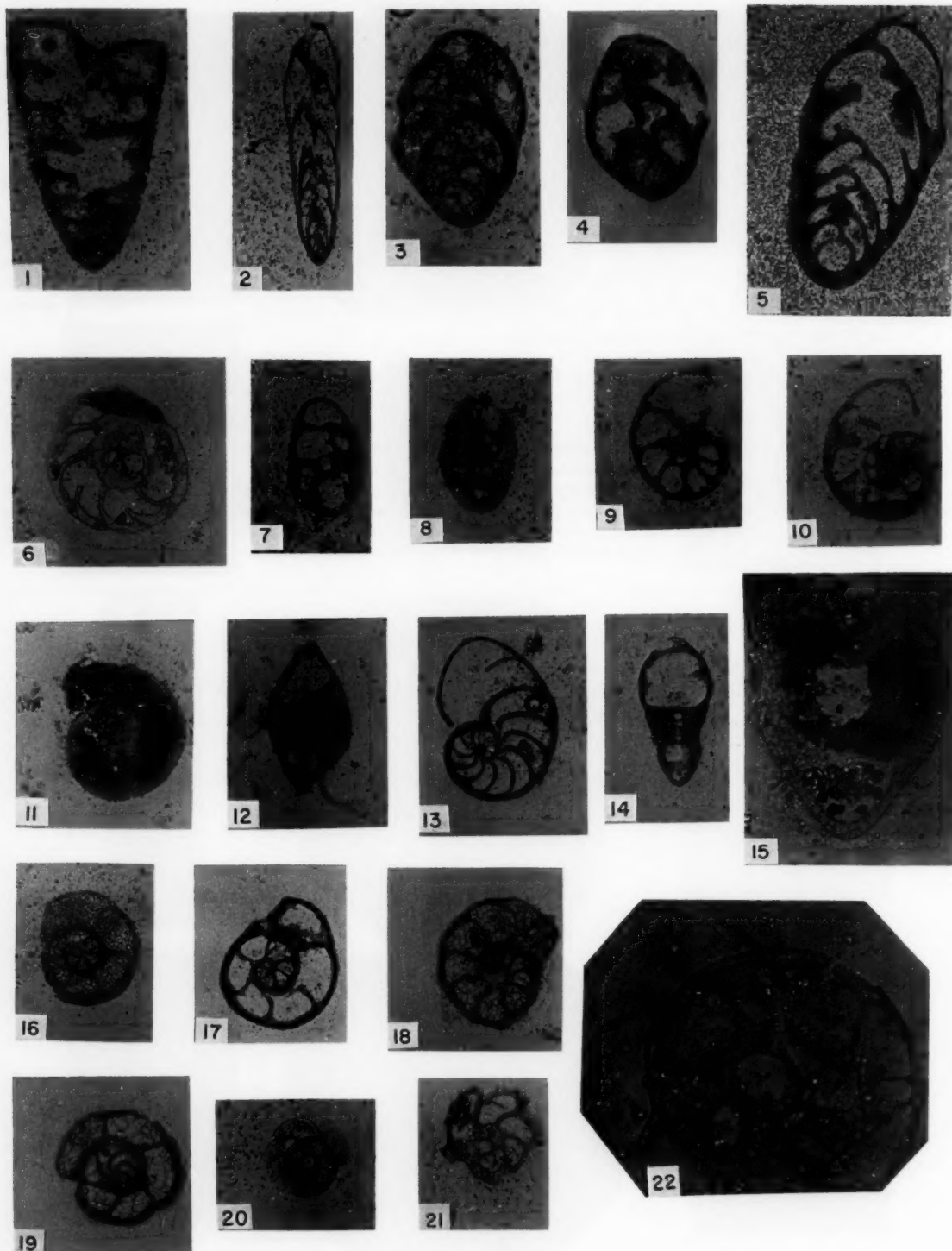
7 *Rotalia* sp.

Horizontal section,  $\times 55$ . IT 78; Recent, Borneo.

8 *Ammonia* ("Streblus") *beccarii* (Linné)

Vertical section,  $\times 55$ . IT 77; Pliocene, Israel.







## LAMELLAR FORAMINIFERA

### Family Nonionidae

Little is known of the phylogeny of this family, which is actually a misfit in any superfamily. It includes mainly granular generasuch as *Nonion*, *Nonionella* and *Astrononion*, as well as the radiate *Protelphidium*. Smout (1954) has stated that the Nonionidae are not lamellar.

### Family Alabaminidae

Hofker includes the genera *Alabamina*, *Gyroidina*, and *Rotalia*, and possibly also *Gyroidinoides*, in this family. *Rotalia*, however, is the familiotypus of the radiate Rotaliidae, and *Gyroidinoides* is a bilamellid, probably belonging to the Gavelinellidae. Specimens of true

## PLATE 2

- 1 *Marssonella* cf. *oxycona* (Reuss)  
Vertical section,  $\times 55$ ; note non-lamellar structure, and inner "fibrous" layer lining previous septum also.  
IT 56; Maestrichtian, Bavaria.
- 2 *Virgulina schreibersiana* Czjzek  
Vertical section,  $\times 55$ . IT 59; Miocene, Vienna Basin.
- 3 *Praebulimina laevis* (Beissel)  
Vertical section,  $\times 55$ . IT 57; Maestrichtian, Sweden.
- 4 *Praebulimina laevis* (Beissel)  
Vertical section,  $\times 55$ . IT 58; Maestrichtian, Israel.
- 5 *Bolivina incrassata* Reuss  
Vertical section,  $\times 55$ . IT 60; Maestrichtian, Israel.
- 6 *Cassidulina* cf. *laevigata* d'Orbigny  
Horizontal section,  $\times 55$ . IT 98; Recent, California.
- 7-10 *Ceratobulimina* (*Ceratocancris*) *stellata* Bandy  
7-8, vertical sections; 9-10, horizontal sections; all  $\times 55$ . IT 32-35; Claiborne, Texas.
- 11 *Höglundina elegans* (d'Orbigny)  
Horizontal section,  $\times 55$ . IT 115; Neogene, Morocco.
- 12 *Höglundina elegans* (d'Orbigny)  
Vertical section,  $\times 55$ . IT 116; Neogene, Israel.
- 13 *Nonion boueanum* (d'Orbigny)  
Horizontal section,  $\times 55$ . IT 49; Miocene, Vienna Basin.
- 14 *Nonion boueanum* (d'Orbigny)  
Vertical section,  $\times 55$ . IT 54; Miocene, Styria.
- 15 *Nonion* cf. *boueanum* (d'Orbigny)  
Vertical section,  $\times 240$ . IT 53; Miocene, Vienna Basin.
- 16 *Alabamina wilcoxensis* Toulmin  
Horizontal section,  $\times 55$ . IT 120; Lower Eocene, Israel.
- 17 *Alabamina wilcoxensis* Toulmin  
Horizontal section,  $\times 55$ . IT 118; Wilcox, Alabama.
- 18 *Osangularia lens* Brotzen  
Horizontal section,  $\times 55$ ; note areal apertures in section. IT 117; Danian, Sweden.
- 19 *Eponides umbonatus* (Reuss)  
Horizontal section,  $\times 55$ . IT 94; Lower Eocene, Israel.
- 20, 22 *Epistominella* sp.  
Horizontal section; 20,  $\times 55$ ; 22,  $\times 240$ . IT 123; Pliocene, California.
- 21 *Siphonina reticulata* (Czjzek)  
Horizontal section,  $\times 55$ . IT 93; Pliocene, Israel.

*Gyroidina* have not been examined by this writer. *Osangularia* is best included in the Alabaminidae, especially on account of its internal organization (such as the infundibulum and tectum; see Brotzen, 1942, 1948), and because the family Parrelloididae Hofker is invalid (see below). *Alabamina* has granular walls (Haynes, 1956), and the same is true of *Osangularia*.

#### Family Eponididae

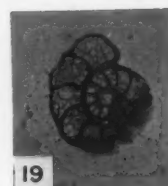
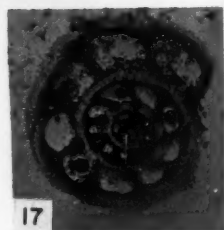
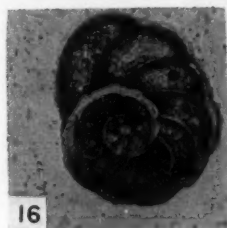
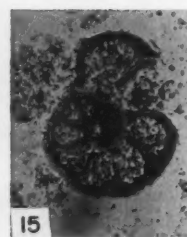
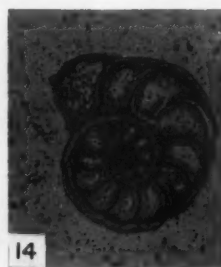
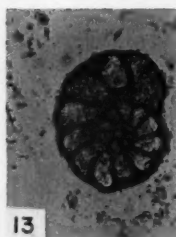
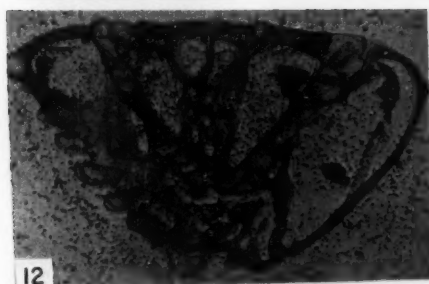
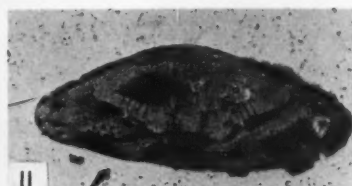
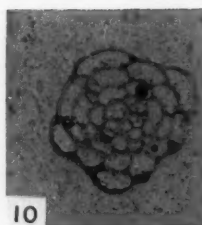
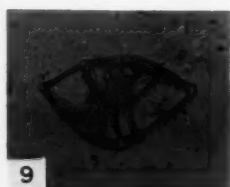
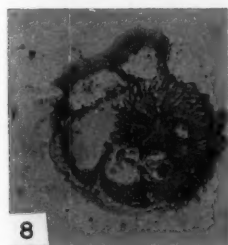
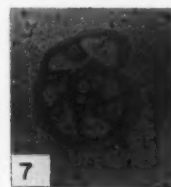
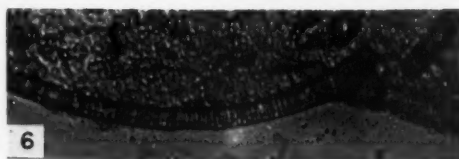
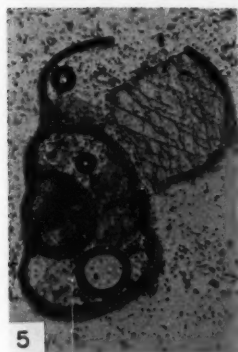
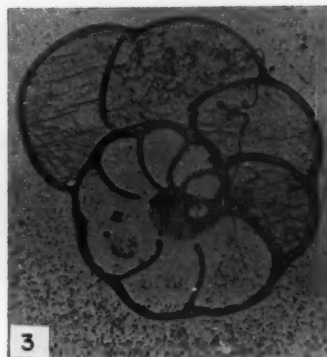
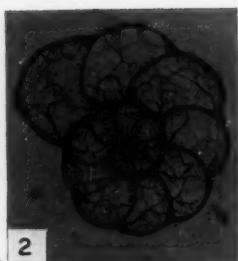
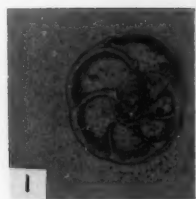
Hofker includes in this family the genera *Eponides*, *Buccella*, and *Pseudoparella*. The two latter genera seem to have radiate walls; some species of *Eponides* have radiate walls, but most of them have granular ones. The position of *Poreponides* is uncertain; it has radiate walls. The radiate genus *Epistominella* may belong here.

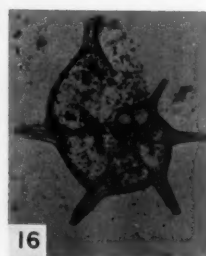
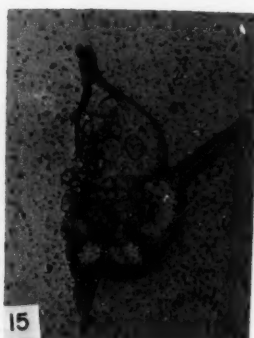
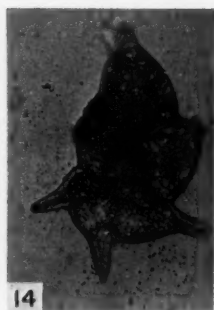
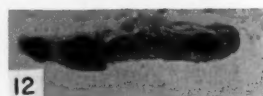
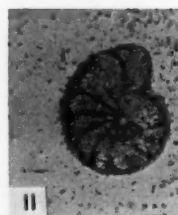
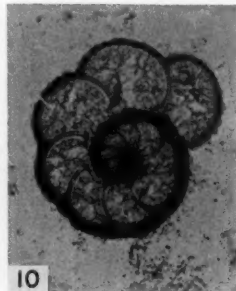
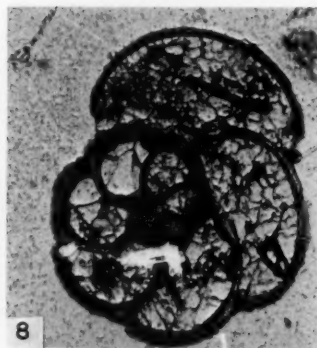
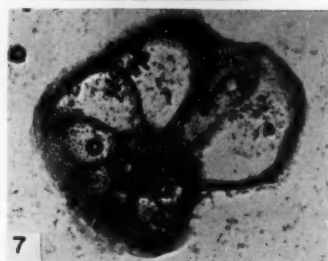
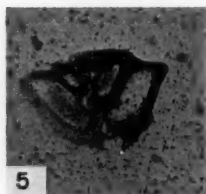
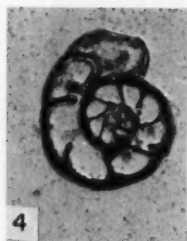
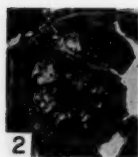
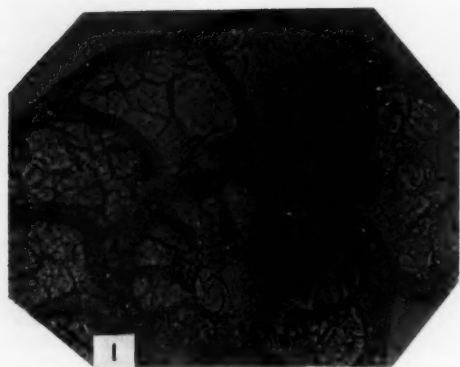
#### Family Parrelloididae

Hofker (1956c) included in this family the genera *Parrelloides*, *Osangularia* and *Planulina*. In the same year (1956d), he included *Parrella* (*Osangularia*) and *Planulina* in the Cibicididae. The familiotypus of the Parrelloididae (*Parrelloides*) is based on a species, *Cibicides hyalinus* Hofker, identical in structure (according to Hofker) with *Cibicides cookei* (Cushman and Garrett), which is apparently a true *Cibicides*, i.e., a deuteroforaminifate bilamellid (see below, and compare Beckmann, 1954, and Schweighauser, 1953). *Osangularia* has been discussed above; it probably belongs to the Alabaminidae. *Planulina* is a deuteroforaminifate bilamellid, and belongs to the valid family Anomalinidae (see below).

### PLATE 3

- 1 *Discopulvinulina* (*Stomatorbina*?) sp.  
Horizontal section,  $\times 55$ . IT 92; Neogene, Oran.
- 2-6 *Valvulineria californica* Cushman  
2-3, horizontal sections,  $\times 55$ ; 4-5, vertical sections,  $\times 55$ ; 6, horizontal section,  $\times 240$ , showing lamellae.  
IT 36, 43, 38, 46, 43; Miocene, California.
- 7 *Asterigerina* sp.  
Horizontal section,  $\times 55$ . IT 114; Recent, California.
- 8 *Asterigerina* sp.  
Horizontal section,  $\times 55$ . IT 113; Ypresian, Paris Basin.
- 9 *Asterigerina* sp.  
Vertical section,  $\times 55$ . IT 111; Recent, California.
- 10 *Planorbulina mediterraneensis* (d'Orbigny)  
Horizontal section,  $\times 55$ . IT 90; Neogene, Oran.
- 11 *Rotalia* sp.  
Vertical section,  $\times 55$ . IT 126; Montian, Netherlands.
- 12 *Rotalia* sp.  
Vertical section,  $\times 55$ . IT 78; Recent, Borneo.
- 13 *Gavelinella pertusa* (Marsson)  
Horizontal section,  $\times 55$ . IT 66; Maestrichtian, Israel.
- 14 *Gavelinella pertusa* (Marsson)  
Horizontal section,  $\times 55$ . IT 63; Maestrichtian, Germany.
- 15 *Gavelinella pertusa* (Marsson)  
Horizontal section,  $\times 55$ . IT 65; Maestrichtian, Israel.
- 16 *Stensiöina excolata* (Cushman)  
Horizontal section,  $\times 55$ . IT 68; Mendez formation, Mexico.
- 17 *Gavelinopsis* sp.  
Horizontal section,  $\times 55$ . IT 79; Maestrichtian, Israel.
- 18 *Gavelinomon* cf. *pompilioides* (Fichtel and Moll)  
Horizontal section,  $\times 55$ . IT 83; Neogene, Israel.
- 19 *Gyroidinoides pseudosimiensis* Reiss  
Horizontal section,  $\times 55$ . IT 99; Campanian, Israel.







## LAMELLAR FORAMINIFERA

### Family Siphoninidae

This family includes *Siphonina*, *Siphoninella*, *Siphoninoides*, and *Pulsiphonina*. Only the last-named genus has granular walls (see Wood, 1949; Haynes, 1956).

The genus *Rosalina* probably belongs here, but it has granular walls (Haynes, 1956). The validity of the family is questionable (see also Glaessner, 1954).

### B. DEUTEROFORAMINATE FAMILIES:

#### Family Conorbidae

According to Hofker, this family includes the genera *Conorboides*, *Neoconorbina*, and the apparently invalid genus *Discobolovina*. The latter genus was erected by Hofker to include the genera *Patellina*, *Patellinella*, and *Patellinoides*, all of which have radiate wall structure.

#### Family Pulvinulinidae

According to Hofker, the genera *Discopulvinulina*, *Conorbella*, *Mississippina* and *Hanzawaia* belong here. The family is invalid for formal nomenclatural reasons. Furthermore, some species of apparently typical *Discopulvinulina* have been found by this writer to have bilamellid structure (see also Reiss, 1957a). Some species of *Discopulvinulina* apparently belong to other genera, e.g., *Stomatorbina* (Bermudez, 1952). The above-mentioned genera have radiate walls.

## PLATE 4

- 1 *Gyroidinoides pseudosimiensis* Reiss  
Horizontal section,  $\times 240$ , showing bilamellid structure. IT 99; Campanian, Israel.
- 2 *Gyroidinoides* sp.  
Horizontal section,  $\times 55$ , showing lamellae. IT 70; Maestrichtian, Israel.
- 3 *Pseudovalvulineria lorneiana* (d'Orbigny)  
Horizontal section,  $\times 100$ . IT 1; Campanian, Paris Basin.
- 4-5 *Globorotalites* sp.  
4, horizontal section,  $\times 55$ ; 5, vertical section,  $\times 55$ . IT 100, IT 22; Campanian, Paris Basin.
- 6 *Discopulvinulina*? sp.  
Vertical section,  $\times 55$ , showing bilamellid structure. IT 91; Miocene, Morocco.
- 7 *Cibicides* sp.  
Horizontal section,  $\times 55$ . IT 103; Miocene, Styria.
- 8 *Cibicides beaumontianus* (d'Orbigny)  
Horizontal section,  $\times 55$ . IT 104; Maestrichtian, Sweden.
- 9 *Planulina ariminensis* (d'Orbigny)  
Horizontal section,  $\times 55$ . IT 62; Pliocene, Israel.
- 10 *Anomalinoides* (*Gavelinella*?) *danica* (Brotzen)  
Horizontal section,  $\times 55$ . IT 67; Danian, Sweden.
- 11 *Anomalinoides*? *acuta* (Plummer)  
Horizontal section,  $\times 55$ . IT 105; Midway, Texas.
- 12 *Planulina ariminensis* (d'Orbigny)  
Vertical section,  $\times 55$ . IT 89; Pliocene, Israel.
- 13 *Globigerina* sp.  
Vertical section,  $\times 100$ . Recent, Atlantic Ocean.
- 14 *Appllinella dumblei* (Weinzierl and Applin)  
Horizontal section,  $\times 55$ . IT 97; Middle Eocene, Israel.
- 15 *Appllinella dumblei* (Weinzierl and Applin)  
Horizontal section,  $\times 55$ . IT 80; Middle Eocene, Aquitaine Basin.
- 16 *Hantkenina alabamensis* Cushman  
Horizontal section,  $\times 55$ . IT 76; Jackson, Alabama.

Family **Valvulineridae**

Hofker includes here the genera *Valvulineria* and *Baggina*. Smout has stated that *Valvulineria* does not show obvious thickening of the test. As already pointed out (Reiss, 1957a), this writer has found that *Valvulineria* is distinctly lamellar (see figures). In this writer's opinion, the monolamellid genus *Cancris* belongs to the Valvulineriidae. It does not belong, in any case, to the invalid family Marginolamellidae Hofker (Reiss, 1957a). The genera of the Valvulineriidae have radiate walls. So-called species of *Valvulineria* of Cretaceous and early Tertiary age belong mostly to other genera (e.g., *Quadriformphina* and *Rotamorphina*). They are granular and show buliminid tooth-plates.

Family **Asterigerinidae**

The monolamellid Asterigerinidae are here separated from the bilamellid Amphisteginidae (as has already been done by Sigal, 1952). *Reinholdella*, *Asterigerina*, *Asterigerinata* and *Heminwayina* apparently belong to the

Asterigerinidae (compare, however, Hofker, 1956d). All have radiate walls. The genus *Nuttallides* also apparently belongs here.

Family **Planorbulinidae**

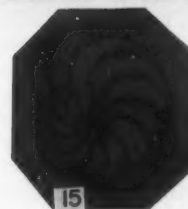
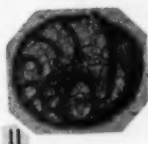
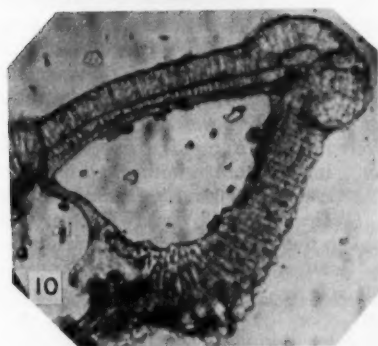
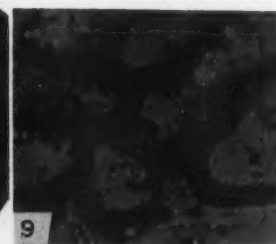
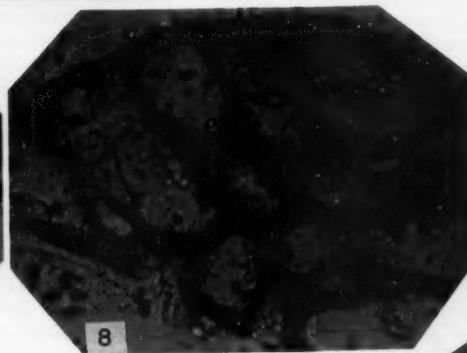
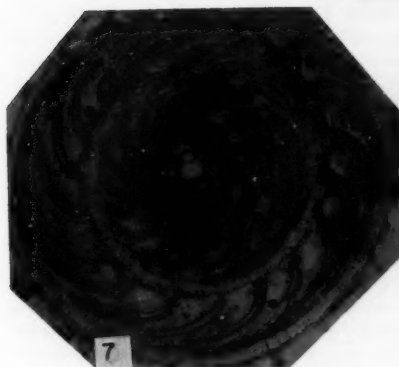
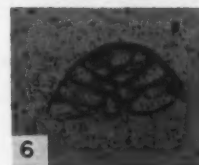
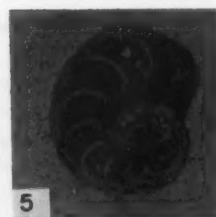
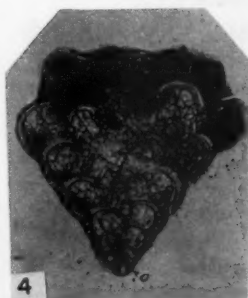
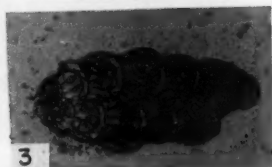
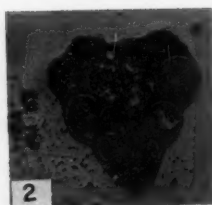
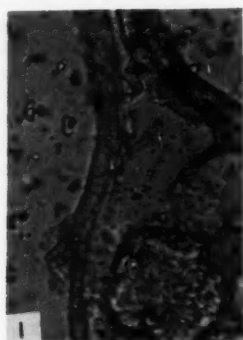
The genera *Planorbulina* and *Planorbulinella* have radiate walls, and the latter are apparently single. The material available to this writer was not sufficient for a detailed examination of the genera usually assigned to this family. The same applies to *Linderina* and *Halkyardia*. Smout (1954) states that the Planorbulinidae have single septa, and he includes the genus *Linderina* in this family.

Superfamily **Rotaliidea** Glaessner, emend. Smout  
Plate 1, figures 7-8; plate 3, figures 11-12; plate 5, figures 12, 15

This superfamily has been analyzed in detail by Smout (1954, 1955, 1956), and no further remarks are necessary here.

## PLATE 5

- 1 *Applina dumblei* (Weinzierl and Applin)  
Horizontal section,  $\times 240$ , showing lamellar structure. IT 80; Middle Eocene, Aquitaine Basin.
- 2-4 *Pseudotextularia varians* Rzehak  
Vertical sections,  $\times 55$ , showing bilamellid structure. IT 108, IT 110, IT 86; Maestrichtian, Aquitaine Basin.
- 5 *Planomalina buxtoni* (Gandolfi)  
Horizontal section,  $\times 55$ , showing bilamellid structure. IT 75; Vraconian, Algeria.
- 6, 8-9 *Cymbaloporeta* sp.  
Vertical sections, showing bilamellid structure; 6,  $\times 55$ ; 8-9,  $\times 240$ . IT 95; Recent, California.
- 7 *Amphistegina lessonii* d'Orbigny  
Horizontal section,  $\times 55$ , showing bilamellid structure. IT 106; Miocene, Vienna Basin.
- 10 *Globorotalia menardii* (d'Orbigny)  
Vertical section,  $\times 110$ , showing bilamellid structure and carinal canal. IT 8; Recent, Atlantic Ocean.
- 11 *Valvulammina picardi* Henson  
Horizontal section,  $\times 55$ , showing non-lamellar structure. IT 81; upper Cenomanian, Israel.
- 12 *Cuvillierina eocenica* Debourle  
Horizontal section,  $\times 55$ , showing canal system. IT 132; Ypresian, Aquitaine Basin.
- 13 *Pyrgo* sp.  
Horizontal section,  $\times 21$ , showing non-lamellar single-layered walls. IT 82; Neogene, Italy.
- 14 *Orbitolites complanatus* Lamarck  
Horizontal section,  $\times 55$ , showing non-lamellar double-layered walls. IT 84; Lutetian, Paris Basin.
- 15 *Elphidium* sp.  
Horizontal section,  $\times 55$ , showing canal system. IT 135; Miocene, Israel.



Superfamily **Bilamellidea** Reiss  
 Plate 1, figures 5-6; plate 3, figures 13-19; plate 4,  
 figures 1-16; plate 5, figures 1-10

This superfamily has been erected (Reiss, 1957a) for those members of the superfamily Discorbidea Smout (1954) that show primarily-formed double septa. It is here formally emended to include both radiate and granular forms. The main characteristics of this superfamily have been discussed above.

#### Family **Gavelinellidae**

The following genera should be included here: *Gavelinella*, *Pseudovalvulinaria*, *Gavelinopsis*, *Gavelinonion Stensiöina*, and *Gyroidinoides*. As has been seen, the double septa are by no means characteristic of this family, as claimed by Hofker (op. div.). The genera of the Gavelinellidae are obviously closely related one to the other, and have distinctive apertural characteristics. Most of them have granular structure, although some of them seem to have had a radiate structure, which became obliterated and granular during fossilization. Under the polarizing microscope, topotypes of *Pseudovalvulinaria lorneiana* (d'Orbigny) show features (especially extinction) that appear to point to an originally radiate structure. This writer has seen specimens of unquestionable rotaliids with typically radiate structure, which show in section the same compact and granular wall structure (e.g., *Operculina*, *Rotalia*) (compare also Reichel, 1956, and Smout, 1956). Hofker includes *Pseudovalvulinaria* in *Gavelinella*; this view is not followed here. *Hedbergina* is probably related to the Gavelinellidae, and is apparently the earliest globotruncanine genus. *Gyroidinoides* can be defined as a *Gavelinella* with a high umbilical side. The position of the genus *Globorotalites* is uncertain; it is a bilamellid, but it has small tooth-plates and a granular wall structure. It may be an early gavelinellid.

#### Family **Anomalinidae**

Hofker has placed *Planulina* in the Parrelloididae, *Cibicides* in the Cibicididae, and most of the species of *Anomalinoides* in *Gavelinella*, and has retained the family Anomalinidae for such forms as *Anomalinoides acuta* (Plummer), which, according to Hofker (1956c), has "single septa." In the same year (1956d), Hofker stated that there is no essential difference between *Anomalina*, *Planulina*, *Anomalinoides*, and *Cibicides*, and he placed all these genera in the Cibicididae, which, according to Hofker, have "single septa" and belong to the "ordo" Biforaminata. It has already been stated above that this writer agrees with Glaessner (1954) with regard to the deutoforaminate nature of the aperture of *Cibicides*. Moreover, typical species of *Cibicides*, *Planulina* and *Anomalinoides* in the sense of Hofker (see Hofker, op. div.) have been shown to have distinctly double septa and generally bilamellid structure (see figures). The family Cibicididae therefore becomes meaningless, and the name Anomalinidae is retained. The position of *Anomalinoides* in the sense of Brotzen remains uncertain as

long as no topotype specimens of the genotype have been examined. Some species of *Anomalinoides* may belong to *Gavelinella*, others to *Gavelinopsis*. The existence of a genus *Anomalina* seems doubtful to the writer, especially since all specimens of *Anomalina* ever examined by this writer have been shown to have the apertural characters of *Anomalinoides*. These problems need further study. *Almaena*, *Queraltina* and *Planulinella* belong here. *Planomalina* has canaliculate keels and apertural characters which place it in the Globorotaliidae (Globotruncaninae) (Reiss, 1957a). No specimens of *Anomalinella* were available to this writer.

#### Family **Pulvinulinidae** (pars)

It has been stated above that some typical species of *Discopulvinulina* show bilamellid structure. These may have to be removed to the Gavelinellidae or to a new family.

#### Family **Globigerinidae**

The genera *Globigerina*, *Globigerinella*, *Globigerinelloides*, *Biglobigerinella*, *Globigerinoides*, *Hastigerina*, *Hastigerinella*, *Hastigerinoides*, *Candorbulina*, *Orbulina*, *Globigerinita*, *Globigerinoita*, *Globigerinatheka*, *Sphaeroidinella*, *Plummerita*, and *Rugoglobigerina* seem to belong to this family. *Globigerinatella* is not included by Hofker in this family. A revision of the Globigerinidae is being carried out at present by this writer. This family may actually be a polyphyletic group, and many so-called genera may actually represent forms of a "plexus" in the sense of Sigal (1952). The genus *Globigerina* is doubtless composed of several genera, which must be defined and separated. As pointed out by other authors and by this writer (1957a), the Tertiary species of *Globigerina* s.l. must be separated from the pre-Danian species on the basis of their wall structure (pores and ornamentation) and apertural characters. *Rugoglobigerina* is included, for the time being, in the Globigerinidae and not in the Globotruncaninae, as has been done by Bronnimann and Brown (1956). *Globigerinella*? ("Nonion") *micra* (Cole) probably belongs to the Hantkeninidae. It has the wall structure of that family, and evidence at hand indicates that *Hantkeninella* was derived directly from this species. In all Globigerinidae the spaces between the main lamella and the inner lining are very narrow and hardly visible in section, leaving only a distinct but rather small peristomal canal. This is also true of all Gümbelinidae and Hantkeninidae. Smout (1954) has stated that the Globigerinidae do not show thickening of the test. As already shown by this writer elsewhere (Reiss, 1957a), all Globigerinidae have lamellar structure.

#### Family **Hantkeninidae**

The genera *Hantkenina*, *Aragonella*, *Applinelina*, *Hantkeninella*, and *Cribohantkenina* belong here. The position of *Schackoia* is uncertain; it may belong to the Cretaceous group to which *Plummerita* belongs. *Globigerinella*? *micra* (Cole) is apparently a hantkeninid, and may have to be included in a new genus.



## LAMELLAR FORAMINIFERA

### Family Gümbelinidae

The genera *Gümbelina*, *Pseudogümbelina*, *Ventilabrella*, *Planoglobulina*, *Pseudotextularia*, and *Gümbelitra* belong here. *Rectogümbelina*, *Gümbelitra*, and *Tubitextularia* have not been examined by this writer. The family seems to be closely related to the Globigerinidae, and is essentially Cretaceous. The position of the Danian and Paleocene gümbelinids needs further study. Eocene species of "*Gümbelina*" are actually *Stainforthia*.

### Family Globorotaliidae

This writer (Reiss, 1957a) recognizes two subfamilies, the Globotruncaninae and the Globorotaliinae. The subfamily Globotruncaninae includes the genera *Ticinella*, *Biticinella*, *Thalmaninella*, *Rotalipora*, *Praeglobotruncana*, *Globotruncana*, and *Planomalina*, as well as the recently established genera *Helvetoglobotruncana*, *Globotruncanella*, and *Globotruncanella* Reiss (1957a). *Hedbergina* is one of the earliest forms of this group, and may properly be included in this subfamily, which was regarded by Bronnimann and Brown (1956) as an independent family. *Rugotruncana* (= "*Rugoglobotruncana*") Reiss, 1957a) also belongs here. Bronnimann and Brown include *Rugoglobigerina*, *Trinitella*, and *Kuglerina* in the Globotruncaninae. The first genus is here included in the Globigerinidae, and no specimens of the two last-named genera have been examined by the present writer. The subfamily Globorotaliinae is at present under revision by this writer. It seems to include *Globorotalia*, *Truncorotalia*, at least some species of *Turborotalia*, and probably *Truncorotaloides*. Hofker included the Globorotaliidae and the genus *Cancris* in his family Marginolamellidae. That family is invalid and meaningless, however, since *Cancris* is, as pointed out above, a monolamellid, probably related to *Valvulinaria* (Reiss, 1957a).

### Family Cymbaloporettidae

The genera *Cymbaloporella* and *Cymbaloporeta* are bilamellids. *Cymbalopora* has not been examined by this writer; it is regarded by Hofker as arenaceous, not belonging to this family. *Tretomphalus* may belong here or to the Planorbulinidae, or it may be polyphyletic, as claimed by some authors. No specimens suitable for detailed study were available to this writer.

### Family Amphisteginidae

The genera *Amphistegina* and *Eoconuloides* are included here. Photographs and descriptions published by Barker and Grimsdale (1936) and by Cole and Gravell (1952) leave little doubt about the structure of these genera.

### Family Helicolepidinidae

Possibly this family should be united with the Amphisteginidae. The family Helicolepidinidae includes the genera *Helicostegina*, *Eulinderina*, *Helicolepidina*, and *Pseudolepidina*. Sigal (1952) includes *Boreloides* here also.

### Family Discocyclinidae

A summary of this family has been given by Sigal (1952). The reader is also referred to the rich literature dealing with this group, listed by Schweighauser (1953).

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**ABSTRACT:** *The distribution of some species of fresh-water ostracodes in Trinidad is discussed. It is possible to recognize five different types of fauna which occur in zones from the headwaters of the rivers down to sea level. This zonation is more or less in accordance with the distribution of the Thecamoebina.*

## Distribution of fresh-water ostracodes in Trinidad

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### INTRODUCTION

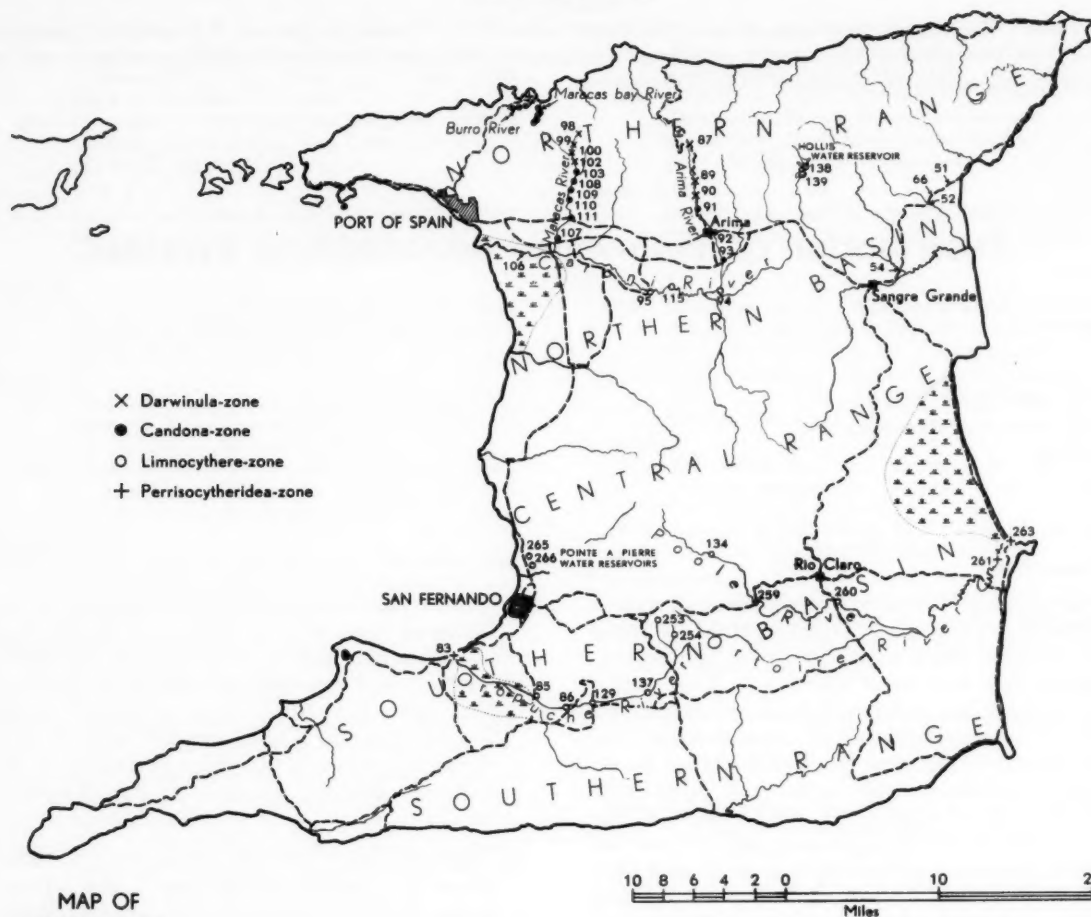
While making a study of the Thecamoebina in samples from the rivers of Trinidad, H. M. Bolli and J. B. Saunders found that a number of samples contained a fair amount of Ostracoda. They turned over to the writer pickings of the sieved residues for study. Unfortunately, nearly all soft parts had disappeared by the time the material could be examined. Moreover, the writer had very little literature on the subject. For these reasons, only a few species could be identified, and it was not possible to make adequate descriptions. Nevertheless, it seemed worth while to publish the results because to date nothing has been published on fresh-water ostracodes from Trinidad.

The writer greatly appreciates all the help he has had from Messrs. Bolli and Saunders, who also permitted him to use all of the data on water conditions which they had collected. Permission from Shell Trinidad, Ltd., to publish this paper is also gratefully acknowledged.

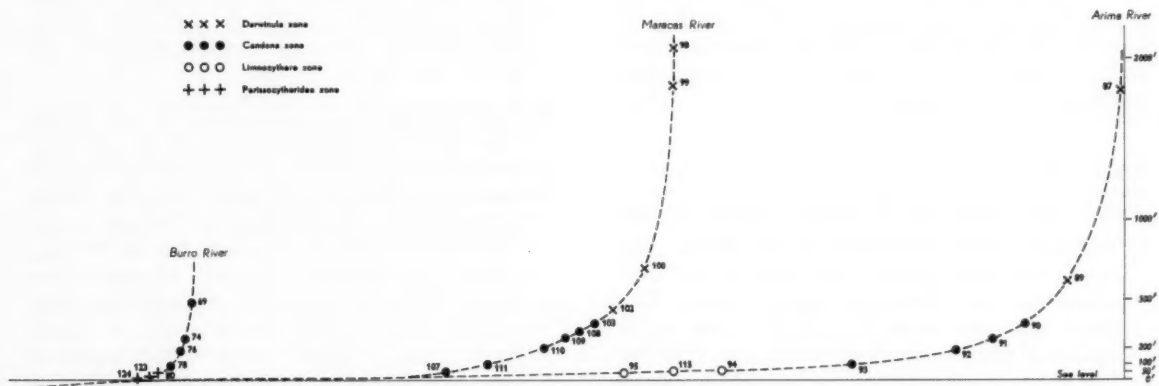
### FAUNAL GROUPS

The ostracode fauna can be divided into five groups:

- 1) *Darwinula* fauna, consisting of the species *Darwinula stevensoni* (Brady and Robertson), *Darwinula* sp., and *Stenocypris major* (Baird). This fauna has been found in a zone in the upper courses of rivers in the Northern Range (2000 feet to 400 feet above sea level), in clear flowing water (chloride content 4–20 parts per million, pH 7–8.5) (see Table 2).
- 2) *Candona* fauna, consisting of the species of the *Darwinula* fauna with the addition of *Dolerocypris*? cf. *fasciata* (G. W. Müller), *Candona* cf. *fabaeformis* (Fischer), and *Cypridopsis* cf. *vidua* (O. F. Müller). This fauna is found in clear to slightly turbid flowing water in a zone between 600 feet and 50 feet above sea level (chloride content 12–27 parts per million, pH 7.8–8.4) (see Tables 1 and 2).
- 3) *Limnocythere* fauna, consisting of the species *Limnocythere* sp., *Ilyocypris bradyi* Sars, *Cypria* cf. *exsculpta* (Fischer), *Cypria* cf. *ophthalmica* (Jurine), *Physocypris*? sp., *Cypris* cf. *ornata* G. W. Müller, *Cypris* cf. *lilljeborgi* G. W. Müller, *Cypridopsis* cf. *vidua* (O.F. Müller), and *Stenocypris major* (Baird). This fauna occurs in slowly flowing to semi-stagnant, usually turbid water, in flat or slightly hilly country (chloride content variable, pH 6.7–8) (see Tables 2, 3, 4).
- 4) *Perissocytheridea* fauna, consisting of the species *Perissocytheridea matsoni* (Stephenson), *Perissocytheridea subrugosa* (Brady), some species from the *Candona* or *Limnocythere* faunas, and some marine forms from the normal fauna of the seas around Trinidad, for example, *Basslerites berchoni* (Brady), *Cativella semitranslucens* (Crouch), *Hemicythere confragosa* Edwards, *Loxoconcha* sp., and *Leptocythere ochracea* (Brady). This fauna occurs in slowly flowing, usually turbid water in the mouths of rivers near or below the highest level of tidal influence (chloride content above 150 parts per million, pH 6.6–7.5) (see Tables 1 and 2).



TEXT-FIGURE 1



TEXT-FIGURE 2

DISTRIBUTION OF OSTRACODE ZONES IN SOME RIVER PROFILES



## FRESH-WATER OSTRACODES IN TRINIDAD

DISTRIBUTION OF OSTRACODA AND OF WATER CONDITIONS IN BURRO AND MARAOGAS BAY RIVERS,  
NORTHERN TRINIDAD

		<i>Camisia cf. foliiformis</i> (Fischer)	<i>Dreissena sinensis</i> (Beady & Robertson)	<i>Dreissena</i> sp.	<i>Diapomphus cf. fasciata</i> (Müller)	<i>Diapomphus major</i> (Baird)	<i>Perissophoridae natans</i> (Stephansson)	<i>Perissophoridae natans</i> (Beady)	NaCl (parts per million)	Chloride (parts per million)	pH	
Barro River	69*	/		x					45	27	8.3	Clear, flowing
	74**	x	x	x					32	20	8.2	23 22
	76	/	x						32	20	8.6	23 22
	77		x	/	/							23 23
	78	x										23 23
	79	x			/							23 22
	80		/	/		x						22 22
	123					x			284	172	6.6	relatively clear, flowing
	124	x				O	x		258	156	7.5	23 23
	56	O		x	x				32	20	7.4	clear, flowing
Maraca Bay River	57	/	x	/	/				90	55	7.1	22 22
	63	/	x	/	/				19	12	8.3	22 23
	64	x	/	/	/							22 22
	43	O	x	/						12	7.9	22 22

\* Chemical characteristics taken from sample 68, in close proximity.

\*\*) Chemical characteristics taken from sample 75, in close proximity.

/ single specimen

× rare (2-5 specimens)

○ common (5–20 specimens)

DISTRIBUTION OF OSTRACODA AND OF WATER CONDITIONS IN RIVERS ON THE SOUTH FLANK OF THE NORTHERN RANGE

		<i>Gambusia cf. fasciatus</i> (Fischer)	<i>Cyprinodont cf. rubrus</i> (Müller)	<i>Oryzias</i> sp.	<i>Daphnia stenocephala</i> (Bridges & Robertson)	<i>Daphnia</i> sp.	<i>Daphnia?</i> cf. <i>fasciata</i> (Müller)	<i>Hyalella hesperis</i> Sars	<i>Limnodynastes</i> sp.	<i>Stenonema major</i> (Huxley)	NaCl (parts per million)	Chloride (parts per million)	pH	
Arizona River	87				○	×				○	4	7.5	Clear, fast-flowing	
	89				○	○	×		×	32	20	8.2	22 22 22	
	90				○	○			/	13	8	8.5	22 22 22	
	91	/			/		×		/				22 22 22	
	92				×					26	16	8.0	22 22 22	
	95	×			○	/			×				22 22 22	
Crown River	94		×			/		○	×	19	12	7.7	Turbid, flowing	
	115	×		/			○	×	×	19	8	7.2	22 22	
	95	/	/					●	×	19	12	7.8	22 22	
Maraca Valley	Arasco River	98			/	/							clear pool between waterfalls	
		99			×	×							22 22 22 22	
		100			/	×	×						clear, fast-flowing	
		102			×				/				22 22 22	
		103			●		/						22 22 22	
	Maraca River	108		×	●	×	/			39	23	8.0	22 22 22	
		109			●	×				32	10	7.8	22 22 22 22	
		110			●	○			○	39	12	8.0	22 22 22	
		111	/	/	○	/	/			45	27	8.2	rather turbid, slowly flowing	
		107	/		/			×	×	39	23	8.4	22 22 22 22	

/ single specimen

× rare (2-5 specimens)

○ common (5–20 specimens)

● abundant (more than 10 specimens)

TABLE 3  
DISTRIBUTION OF OSTRACODA AND OF WATER CONDITIONS IN SOUTHERN TRINIDAD RIVER

	<i>Cypris cf. anomala</i> (Fincher)	<i>Alpheoerythra</i> sp.	<i>Cypris cf. ornata</i> Müller	<i>Cypris?</i> sp.	<i>Dreissena staminalis</i> (Brady & Robertson)	<i>Alpheoerythra longis</i> Starn	<i>Lamprocythere</i> sp.	<i>Stenocypris major</i> (Barcl)	<i>Pezomachus setosus</i> (Stephanosau)	<i>Pezomachus setosus</i> (Brady)	<i>Paracyclops leuckarti</i> (Brady)	<i>Canthocamptus curvicauda</i> (Crouch)	<i>Hemicyclops oregonicus</i> Edwards	<i>Lamprocythere</i> sp.	<i>Lamprocythere setosus</i> (Brady)	NaCl (parts per million)	Chloride (parts per million)	pH	
253	○	/				○	○											semi-stagnant	
254						○	○											" "	
129						○	×									207	123	7.3	stagnant
86		×	/	/		○	●	○								271	164	8.0	" "
85		×	/	/			×									161	98	7.9	" "
83	×	×					×		×					×		271	164	7.5	turbid, flowing
134							○	×								172	104	6.7	semi-stagnant
259						○	○	×								69	42	7.5	" "
260	/				×	×	○									172	104	7.2	turbid, slowly flowing
261									○	×						271	164	7.5	" "
263	/						○	●	/	×	/	×	×	×	×	291	186	6.6	turbid, flowing

/ single specimen

× rare (2-5 specimens)

○ common (5–20 specimens)

● abundant (more than 20 specimens)

 $t = 1000$ 

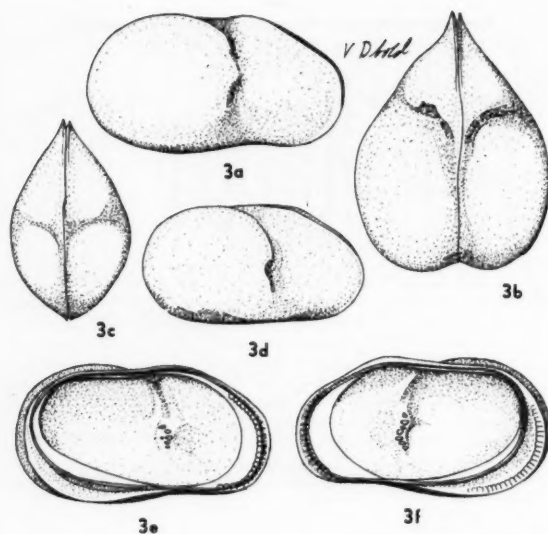
TABLE 4  
DISTRIBUTION OF ONCHOCODA IN SOME WATER RESERVOIRS IN TRINIDAD

		<i>Cypris</i> cf. <i>armatipes</i> (Fischer)	<i>Cypris</i> cf. <i>aphelodes</i> (Jurine)	<i>Physocystis</i> sp.	<i>Cypridopsis</i> cf. <i>vidua</i> (Müller)	<i>Cypris</i> cf. <i>viridis</i> Müller	<i>Cypris</i> ? sp.	<i>Darwinula stevensi</i> (Brady & Robertson)	<i>Darwinula</i> sp.	<i>Lamyspha</i> sp.	<i>Stomatopora major</i> (Baird)	
Hollis Reservoir	138					x	x	x	/	x	/	relatively clear, non-flowing
	139	o		o	x	o	o			●	x	22 22 22
Pointe-à-Pierre Reservoir	265	x	/	x	x	o	/			●	o	slightly turbid, non-flowing
	266				o	/				●		22 22 22

TABLE 3

DISTRIBUTION OF OSTRACODA AND OF WATER CONDITIONS IN SOME RIVERS IN NORTHERN TRINIDAD

		<i>Candona cf. fabaeformis</i> (Fischer)	<i>Candona cf. pectus</i> Harweg	<i>Oxytropis cf. rubus</i> (Müller)	<i>Dreissena polymorpha</i> (Brady & Robertson)	<i>Dreissena</i> sp.	<i>Diacyclops? cf. finensis</i> (Müller)	<i>Limnocyclus</i> sp.	<i>Mesocyclops?</i> sp.	NaCl (parts per million)	Chloride (parts per million)	pH
Matara River	51	x	/	x	/	x	/	/	/	26	16	8.0
Rio Grande trib.	66	/	/	/	/	/	/	/	/	38	35	8.0
Rio Grande	52	/	/	x	x	/	/	/	/	26	16	8.2
Orouche River	54	x	/	/	/	/	x	/	/	26	16	8.2
Caroni River	106									499	266	8.8



TEXT-FIGURE 3  
*Metacypris?* sp.

- a Right valve view of complete female carapace.
- b Dorsal view of same carapace.
- c Dorsal view of complete male carapace.
- d Right valve view of same specimen.
- e Interior of left valve of female.
- f Interior of right valve of female.

5) *Metacypris* fauna, consisting of one species of *Metacypris* (?). This type of fauna has been found only in a stagnant drain, separated from the lower Caroni River by a sluice gate (sample 106). The generic determination is questionable, as this species does not possess the typical posterior hinge-tooth of *Metacypris*, and it may belong to the genus *Elpidium* (see text-figure 3a-f). Single specimens of this species have been found in a few samples north of Sangre Grande, together with species of the *Darwinula*, *Candona*, and *Limnocythere* faunas. How far some of these species may have been carried downstream is unknown. Locality 106 stands out among the others because of its relatively high salinity and pH (see Table 5).

#### DISTRIBUTION OF FAUNAL ZONES

1) *Darwinula* zone: This zone is found in the Arima and Maracas Rivers (see text-fig. 2), including the Acono, a tributary of the Maracas River, from the headwaters and some higher pools, at

about 2000 feet, down to about 400 feet above sea level. It corresponds to zone I of Bolli and Saunders (1954) in these rivers.

#### 2) *Candona* zone:

- a) This zone lies below the *Darwinula* zone in the Arima and Maracas Rivers, from about 400 feet down to about 50 feet above sea level. Here it corresponds to zone II of Bolli and Saunders (1954).
- b) This zone also occurs in the Burro and Maracas Bay Rivers, from the headwaters, at about 600 feet, down to the zone of tidal influence. It corresponds here to zone I of Bolli and Saunders (1954). As the *Darwinula* fauna appears to represent a special development of the *Candona* fauna, it is not surprising to find a few samples with only the *Darwinula* fauna below the highest occurrence of the *Candona* fauna (see Table 2, samples 92 and 110).

#### 3) *Limnocythere* zone:

- a) This zone is found in the Caroni River, between its confluences with the Arima and Maracas Rivers. It corresponds more or less to zone III of Bolli and Saunders (1954). In the lower part of the Caroni River, which belongs to zone IV, no ostracodes have been found except at locality 106 (*Metacypris* fauna).
- b) This zone also occurs in the south of Trinidad, from the headwaters of the Oropouche and Ortoire-Poole Rivers, up to a maximum of 200 feet above sea level, down to the zone of tidal influence.
- c) Another occurrence of this zone is in the Pointe-à-Pierre and Hollis water reservoirs. The absence of *Ilyocypris bradyi*, and the presence in these lakes of *Cypris* cf. *ophthalmica* and *Cypris* cf. *lilljeborgi*, which have not been found in the river samples, points to slightly different conditions. Unfortunately, no chemical analyses of the water are available.

4) *Perissocytheridea* zone: This zone occurs in the mouths of the Burro, Oropouche, and Ortoire Rivers, near or below the level of highest tidal influence. It corresponds roughly to zone IV of Bolli and Saunders (1954).

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ABSTRACT: The holothurian genus *Achistrum* is subdivided, on the basis of the terminal loop, into the subgenus *Achistrum* sensu stricto and three new subgenera, *Spinrum*, *Cancellrum*, and *Aduncrum*. Their relationships are discussed.

## Subgenera of the holothurian genus *Achistrum*

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### INTRODUCTION

Frizzell and Exline (1955) erected the family Achistridae for all holothurian sclerites referred to the genus *Achistrum*, which they emended (Frizzell and Exline, 1955) to include only spicules in the form of hooks, with eye, shank and spear, of Etheridge's (1881) original assemblage, which also contained holothuroid sieve-plates. In a study of British Oxfordian forms (Hodson, Harris and Lawson, 1956, p. 339), three well-defined subdivisions of the genus *Achistrum*, based on the nature of the terminal loop (eye), were recognized, and Frizzell (personal communication, 1957) suggested that they should be given subgeneric, if not generic, rank. A further study of forms from the English Bathonian (Hampton, MS.) has revealed the existence of yet another subdivision, and it now seems expedient to follow Frizzell's suggestion and erect subgenera for these groups, for inclusion in the forthcoming section on holothurians of the "Treatise on Invertebrate Paleontology."

### SYSTEMATIC PALEONTOLOGY

Phylum ECHINODERMATA

Class HOLOTHUROIDEA

Family ACHISTRIDAE

Genus *Achistrum* Etheridge, 1881, emend. Frizzell and Exline, 1955

*Achistrum* Etheridge, emend. FRIZZELL AND EXLINE, 1955, Missouri, Univ., School Mines and Met., Bull., Tech. Ser., no. 89, p. 93.

**Definition:** Sclerites in form of hooks, with terminal loop, shank and spear; length about 0.20–2.25 mm.

**Type species:** *Achistrum nicholsoni* Etheridge, 1881, p. 195, pl. 5, fig. 7a–b.

**Stratigraphic distribution:** Carboniferous (Mississippian) to Jurassic (Oxfordian).

Subgenus *Achistrum* Etheridge, sensu stricto  
Hampton  
Text-figures 1–2

*Achistrum* "Group 1," HODSON, HARRIS AND LAWSON, 1956, Geol. Mag., vol. 93, no. 4, p. 339.

**Definition:** *Achistrum* with terminal loop empty.

**Type species:** *Achistrum nicholsoni* Etheridge, 1881, p. 195, pl. 5, fig. 7a–b.

**Stratigraphic distribution:** Carboniferous (Mississippian) to Jurassic (Oxfordian) of northern Europe and America.

**Remarks:** The subgenus *Achistrum* is erected to include the following species: *Achistrum nicholsoni* Etheridge (Carboniferous), *Achistrum brownwoodensis* (Croneis) (Carboniferous and Permian), *Achistrum ludwigi* (Croneis) (Carboniferous), *Achistrum permianum* (Spandel) (Permian), *Achistrum triassicum* Frizzell and Exline (Triassic), *Achistrum issleri* (Croneis) (Liassic and Oxfordian), and *Achistrum bathonianum* Frizzell and Exline (Bathonian). *Achistrum* (*Achistrum*) is apparently the stock from which the specialized subgenera of the Lower and Middle Jurassic developed.

Subgenus *Spinrum* Hampton, new subgenus  
Text-figures 3–4

*Achistrum* "Group 2," HODSON, HARRIS AND LAWSON, 1956, Geol. Mag., vol. 93, no. 4, p. 339.

**Definition:** *Achistrum* with terminal loop occupied by two thorn-like processes.

**Type species:** *Achistrum bartensteini* Frizzell and Exline 1955, p. 94, pl. 4, figs. 5–7.

**Stratigraphic distribution:** Jurassic (Liassic) of Germany.

**Remarks:** One species, *Achistrum bartensteini* Frizzell and Exline, is referred to *Spinrum* (Latin *spina* = thorn).



TEXT-FIGURES 1-8

1, *Achistrum* (*Achistrum*) *nicholsoni* Etheridge, type of the subgenus; Lower Carboniferous, Scotland (after Etheridge); dimensions unknown. 2, diagrammatic reconstruction of the terminal loop in *Achistrum* (*Achistrum*);  $\times$  ca. 70. 3, *Achistrum* (*Spinrum*) *bartensteini* Frizzell and Exline, type of the subgenus; Jurassic (Liassic) of Germany (from Frizzell and Exline, after Bartenstein);  $\times$  ca. 33. 4, diagrammatic reconstruction of the terminal loop in *Achistrum* (*Spinrum*);  $\times$  ca. 70. 5, *Achistrum* (*Cancellrum*) *gamma* Hodson, Harris and Lawson, type of the subgenus; Jurassic (Oxfordian) of England (after Hodson, Harris and Lawson);  $\times$  ca. 48. 6, diagrammatic reconstruction of the terminal loop in *Achistrum* (*Cancellrum*);  $\times$  ca. 70. 7, *Achistrum* (*Aduncrum*) *cordatum* Hampton, type of the subgenus; Jurassic (Bathonian) of England (after Hampton, Geol. Mag., in press);  $\times$  ca. 52. 8, diagrammatic reconstruction of the hook-like projections in *Achistrum* (*Aduncrum*);  $\times$  ca. 70.

**Subgenus *Cancellrum* Hampton, new subgenus**  
Text-figures 5-6

*Achistrum* "Group 3," HODSON, HARRIS AND LAWSON, 1956, Geol. Mag., vol. 93, no. 4, p. 339.

**Definition:** *Achistrum* with cross-bar in terminal loop.

**Type species:** *Achistrum gamma* Hodson, Harris and Lawson, 1956, p. 340, text-figs. 12-13.

**Stratigraphic distribution:** Jurassic (Liassic(?), Bathonian and Oxfordian) of England.

**Remarks:** The species *Achistrum gamma* Hodson, Harris and Lawson and *Achistrum monochordata* Hodson, Harris and Lawson are included in *Cancellrum* (Latin *cancelli* = bars or lattice).

**Subgenus *Aduncrum* Hampton, new subgenus**  
Text-figures 7-8

**Definition:** *Achistrum* with terminal loop replaced by two small, incurved, hook-like projections.

**Type species:** *Achistrum cordatum* Hampton MS., Geol. Mag. (in press), text-fig. 9.

**Stratigraphic distribution:** Jurassic (Bathonian) of England.

**Remarks:** *Aduncrum* (Latin *aduncus* = hooked) is erected for one species, *Achistrum cordatum* Hampton. In questioning the generic identity of this species as compared with those subgeneric groups having a terminal loop and "fully developed" spear, Frizzell (personal communication, 1957) stated that the separation of genera is a



## HOLOTHURIAN GENUS ACHISTRUM

matter of grouping, not merely of relationships of certain morphological characters, and that on this basis, because of the extreme modification of the terminal loop and the presumed normal absence of the spear, *Achistrum cordatum* should be set apart from the other groups and considered to be a new genus. The present author, however, considers that the species represents a well-defined subgenus, which probably arose from *Achistrum (Cancellrum) gamma* Hodson, Harris and Lawson in Lower Jurassic time. In the generic and specific determination of *Achistrum*, the degree of development of the spear appears to be a character of little importance, as it has been found to be extremely variable, ranging from highly developed to absent, in many species of the genus.

### DISCUSSION

*Achistrum* ranges from the Carboniferous to the Middle Jurassic, and the possibility of its occurrence in the Cretaceous should not be disregarded, as no complete study concerning the holothuroids of this period has yet been made (Frizzell and Exline, 1955, p. 39). The ranges of the subgenera suggest that *Achistrum (Spinrum)* arose from *Achistrum (Achistrum)* in Upper Triassic to Lower Jurassic (Liassic) time. Both *Achistrum (Cancellrum)* and *Achistrum (Aduncrum)* appear to be specialized developments of *Achistrum (Spinrum)*, probably having been derived from it during the Lower Jurassic. Sclerites of the genus are generally of little stratigraphic value. It should be noted, however, that *Achistrum (Spinrum)*, *Achistrum (Cancellrum)*, and *Achistrum (Aduncrum)* first appear in, and as far as is known are confined to, the Jurassic.

The subgenera proposed here are erected for inclusion within the classification of Frizzell and Exline (1955), and as the present work is based

entirely on the details given in the literature concerning *Achistrum*, reference should be made to Frizzell and Exline (1955, pp. 93-99), Hodson, Harris and Lawson (1956, pp. 339-340), and Hampton (Geol. Mag., in press), for descriptions of the species mentioned above. Although the divisions of *Achistrum* described above represent subgenera in a micropaleontological sense, it is essential to emphasize that zoologically they are probably no more than divisions of a coherent unit, which, in exhibiting morphogenetic features, may reflect the general phylogeny of a long-ranging biological species.

### ACKNOWLEDGMENT

I am deeply indebted to Professor Don L. Frizzell, of the University of Missouri School of Mines and Metallurgy, for suggesting this study and for his helpful advice during its progress.

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ABSTRACT: *The Recent brackish-water foraminiferal faunas of the river estuaries and mangrove swamps of Trinidad are described briefly, and notes on the distribution of species are given. Comparable brackish-water faunas of Miocene and Pliocene age are outlined, and some of the species they have in common with the Recent faunas are described. Comparisons are drawn, where possible, between conditions of deposition of fossil and Recent faunas.*

## Recent foraminifera of mangrove swamps and river estuaries and their fossil counterparts in Trinidad

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### INTRODUCTION

Some Miocene and Pliocene sediments in Trinidad contain a fauna composed of arenaceous foraminifera belonging to the families Reophacidae, Lituolidae, Trochamminidae and Miliolidae, with occasional additions of *Rotalia beccarii* (Linné) and species of *Elphidium*. The purpose of this paper is to show how a comparison of these fossil brackish-water faunas with their Recent counterparts may make it possible to obtain an accurate picture of the depositional environment of some Tertiary sediments. The faunas have by no means been studied exhaustively, and, for this article, a number of the more diagnostic arenaceous species of the environment in question have been selected and described. The genera *Ammobaculites* and *Ammotium* are not considered in detail here. The figured types have been deposited in the collections of the United States National Museum, Washington, D. C.

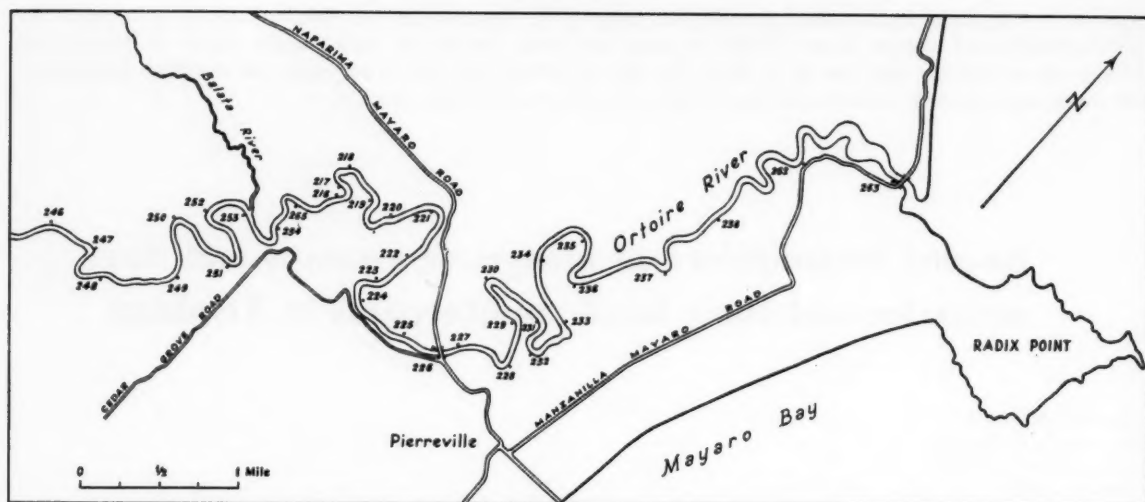
### ACKNOWLEDGMENTS

The author wishes to acknowledge his indebtedness to the following organisations and persons for their help: The Management of The Trinidad Oil Company, Pointe-à-Pierre, Trinidad, who provided laboratory facilities and gave their permission for this work to be published; the Management of Dominion Oil Limited, Port-of-Spain, Trinidad, who released information on Mahaica well no. 1; Dr. J. G. Bursch, who sent the author topotypes of *Praeammoastuta alberdingi* Bursch; Dr. V. Petters, who sent the author hypotypes of *Ammonoastuta caudriae* Petters; Dr. H.

M. Bolli, who read the manuscript and made helpful comments; L. W. Hawkins, with whom the author sampled the Ortoire River; and Miss R. C. Donovan, who prepared the camera-lucida illustrations.

### RECENT FAUNAS

The river estuaries and swamps of Trinidad yield a rich foraminiferal fauna consisting of species adapted to the brackish-water conditions prevailing there. The typical fauna is composed mainly of Lituolidae and Trochamminidae, together with two species of *Miliammina*. At the seaward end of the river estuaries and in the more saline mangrove swamps, the arenaceous species are joined by calcareous foraminifera belonging mainly to the genera *Elphidium* and *Rotalia*. Above the highest tidal influence in the rivers, the foraminiferal fauna is replaced by one composed of the closely related Protozoan group Thecamoebina. These organisms are found plentifully in all the fresh-water bodies of the island (Bolli and Saunders, 1954). They occur also throughout the brackish-water sections in the rivers, but are absent from those brackish swamps having no inflow of fresh water. Saline water is not the true habitat of the Thecamoebina, and their occurrence in it suggests that they have been carried down from fresh-water areas. So far, the tests have not been studied for living protoplasm. A list of the predominant arenaceous species of foraminifera having wide distribution in the brackish waters of Trinidad follows:



TEXT-FIGURE 1

LOCATION OF SAMPLING STATIONS IN THE BRACKISH SECTION OF THE ORTOIRE RIVER, TRINIDAD, B.W.I.

## Reophacidae

*Ammoastuta inepta* (Cushman and Bronnimann)

## Lituolidae

*Haplophragmoides wilberti* Andersen*Ammobaculites* spp., including *A. exilis* Cushman and Bronnimann and *A. dilatatus* Cushman and Bronnimann*Ammotium salsum* (Cushman and Bronnimann)*Trochammina salsa* (Cushman and Bronnimann), emend. Saunders

## Trochamminidae

*Trochammina laevigata* Cushman and Bronnimann*Siphotrochammina lobata* Saunders*Tiphotrecha comprimata* (Cushman and Bronnimann), emend. Saunders*Arenoparrella mexicana* (Kornfeld), emend. Andersen

## Siliciniidae

*Miliammina* cf. *fusca* (H. B. Brady)*Miliammina petila* Saunders, n. sp.

The following brackish-water species have more restricted distribution in Trinidad:

*Haplophragmoides manilaensis* Andersen*Trochammina irregularis* Cushman and Bronnimann, emend. Saunders

The Ortoire River, on the eastern side of Trinidad, has one of the longest sections of tidal influence to be found in the island; it extends for approximately

10 miles. Close sampling of this section (text-fig. 1) demonstrates that the foraminiferal species show a definite zonation (text-fig. 2). *Miliammina petila* Saunders, n. sp., and *Trochammina salsa* (Cushman and Bronnimann), emend. Saunders, range the highest up-river. Almost as long a range is shown by *Haplophragmoides wilberti* Andersen, *Ammobaculites* spp., *Ammoastuta inepta* (Cushman and McCulloch), *Tiphotrecha comprimata* (Cushman and Bronnimann), emend. Saunders, and *Arenoparrella mexicana* (Kornfeld), emend. Andersen. No new species appear until a point about 1- $\frac{1}{2}$  miles from the river mouth is reached. Here, *Trochammina laevigata* Cushman and Bronnimann and *Siphotrochammina lobata* Saunders appear, together with a limited number of calcareous foraminifera, amongst which the genus *Elphidium* predominates. *Gaudryina exilis* Cushman and Bronnimann is found only just within the estuary.

The variation in salinity is very high, especially in the lower part of the brackish section of the river. For example, at Station 238, extreme readings show a range from 27 parts per thousand to 0.2 part per thousand, whereas at Station 226 the recorded range is between 22 parts per thousand and 0.1 part per thousand. In the upper part of the brackish section, readings taken did not exceed 0.04 part per thousand. The figures obtained make it obvious that a true picture of salinity variations in the river can be acquired only from a series of readings taken at all states of the tide and, probably of more importance, at all times during the year, in order to reflect wet- and dry-season conditions. Although



## BRACKISH-WATER FORAMINIFERA IN TRINIDAD

STATION NUMBERS	THECAMERINA	MILIAMMINA PETILA SAUNDERS	TROCHAMMINA SALSA (CUSHMAN & BRONNIMANN)	AMMOBACULITES SPP.	AMMOBACULITES INEPTA (CUSHMAN & BRONNIMANN)	AMMOBACULITES INEPTA (CUSHMAN & BRONNIMANN)	ARENOPARRELLA MEXICANA (KORNFIELD & ANDERSEN)	TIPHOTROCHA COMPRESSA (CUSHMAN & BRONNIMANN)	HAPLOPHRAGMOIDES WILBERTI ANDERSEN	SIPHOTROCHAMMINA LOBATA SAUNDERS	TROCHAMMINA LAEVIGATA CUSHMAN & BRONNIMANN	GAUDRYINA EXILIS CUSHMAN & BRONNIMANN	ELPHIDIUM SPP.
246													
247													
248													
249													
250													
251													
252													
253													
254													
255													
256													
257													
258													
259													
260													
261													
262													
263													

TEXT-FIGURE 2

DISTRIBUTION OF FORAMINIFERA IN THE BRACKISH SECTION  
OF THE ORTOIRE RIVER  
(Locations of stations given in text-figure 1.)

records were obtained for every station, they were collected over too short a period of time to be significant, and they are therefore not quoted in detail here. However, one fact is brought out clearly, and that is the extremely high tolerance of salinity changes exhibited by the foraminiferal species inhabiting the river. A factor that must be borne in mind is the effect of inflowing tidal currents moving foraminiferal tests up-river. The author's experience with water movements in the river leads him to conclude that, although a certain shifting of tests up-river is bound to take place, it will not be of great significance.

Other river estuaries show slightly different faunal assemblages, although the overall picture of salinity tolerance of the species is the same. An example of a river with a somewhat limited fauna of brackish-water arenaceous foraminifera is the Burro River on the northern coast of Trinidad (mentioned by Bolli and Saunders, 1954). In this estuary, the fauna

is made up almost entirely of floods of *Trochammina irregularis* Cushman and Bronnimann, emend. Saunders, and *Miliammina* cf. *fusca* (H. B. Brady), together with *Trochammina salsa* (Cushman and Bronnimann), emend. Saunders, and *Miliammina petila* Saunders, n. sp. For the first two species, this is the only really rich locality known in Trinidad at the present time.

In the Carenage Swamp, on the western coast of Trinidad a few miles west of Port-of-Spain, a fauna is found that has not been paralleled so far in other Recent Trinidad deposits, although a closely similar assemblage has been found in the Miocene Springvale formation (see below). The dominant arenaceous species here are *Haplophragmoides manilaensis* Andersen, *Haplophragmoides wilberti* Andersen, *Arenoparrella mexicana* (Kornfeld), emend. Andersen, and *Siphotrochammina lobata* Saunders, together with other less common forms such as *Gaudryina exilis* Cushman and Bronnimann and *Haplophragmium salsum* Cushman and Bronnimann. Further notes on this area will be found in Saunders (1957).

## FOSSIL FAUNAS

In Trinidad no deep-water deposits were laid down between the Middle Miocene and the Recent. The sands and silts deposited during this time interval carry either a shallow-water or a very shallow-water marine fauna, with occasional shell beds or faunas of a brackish-water nature. The table (text-fig. 3) shows the formations in Trinidad representing the time period from the Miocene to the Recent. Correlations from one formation to another are tentative in most instances, as exact age determinations are difficult because of the paucity of good marker fossils. Further information on the formations mentioned here will be found in Suter (1954) and in Kugler (1953, 1956).

## Cruse formation

On the basis of their foraminiferal faunas, the sands, silts, and clays of this Miocene formation are considered to be of outer-shelf and partly of sub-shelf type. Normally interbedded brackish deposits are absent, as is to be expected. However, the fact that brackish-water faunas of a type found in higher beds were already in existence is shown by the occurrence of balled-up masses of highly lignitic silt in lower Cruse deposits on the southern coast of Trinidad. The lignitic silt occurs as rounded "boulders" up to several feet in diameter embedded in uniform sands that pass, within a few feet, abruptly but normally into regularly bedded clays carrying deep-water arenaceous foraminifera of lower Cruse type. The only reasonable explanation

	NORTHERN BASIN	SOUTH & SOUTHWEST	SOUTH EAST
PLEISTOCENE	TERRACES	TERRACES	TERRACES
PLIOGENE	TALPARO FORMATION	LA BREA FORMATION	
MIOCENE		MORNE L'ENFER FORMATION	MAYARO CLAY
	TELEMAQUE BEDS	FOREST FORMATION	ST. HILAIRE FORMATION
	SPRINGVALE FORMATION	CRUSE FORMATION	CRUSE FORMATION
	LOS ATAJOES BEDS	LENGUA FORMATION	LENGUA FORMATION

TEXT-FIGURE 3

PROBABLE CORRELATION OF YOUNGER BEDS IN TRINIDAD, B.W.I.

is that the boulders are part of a slump-mass bringing material from a not-too-distant shoreline. The brackish-water fauna here is composed almost entirely of *Miliammina telemaquensis* Saunders, n. sp., with the addition of *Arenoparrella mexicana* (Kornfeld), emend. Andersen.

Two wells in one of the southwestern oil fields have yielded cores with a brackish-water fauna composed entirely of *Miliammina telemaquensis* Saunders, n. sp. Cores above and below are of deeper-water origin. The evidence is poor here, but the brackish-water faunas are considered to have slumped into beds of possible upper Cruse age.

It is difficult to draw an accurate analogy between the fossil and Recent depositional environments, because *Miliammina telemaquensis* Saunders, n. sp., the only species that is well represented in the brackish-water sediments of Cruse age, is not found in Recent faunas. However, as the Cruse-age sediments contain a great deal of plant material and still smell strongly of hydrogen sulphide, stagnant marsh conditions are suggested.

#### Morne l'Enfer formation

The sands and silts of the Morne l'Enfer formation are of very shallow-water origin, displaying well developed cross-bedding, impressions of mangrove roots, and bedded lignites. Although the beds are usually barren, there are occurrences of brackish-water faunas, for example in the Coora oil field near Siparia, in the southern part of the island. Here, chocolate-brown lignitic silts carry a fauna of *Miliammina telemaquensis* Saunders, n. sp., with occasional specimens of *Arenoparrella mexicana* (Kornfeld), emend. Andersen.

In the southeastern part of the island, the thin Mayaro clay occurs as a very persistent horizon. It contains a rich brackish-water fauna composed almost entirely of *Miliammina telemaquensis* Saunders, n. sp., and *Arenoparrella mexicana* (Kornfeld), emend. Andersen, with occasional specimens of *Ammonoastuta inepta* (Cushman and McCulloch) and *Ammonobaculites*. Widespread brackish mangrove-swamp conditions must have prevailed over most of the period during which the formation was deposited.

## BRACKISH-WATER FORAMINIFERA IN TRINIDAD

### Springvale formation

This Miocene formation, outcropping in the Central Range and extending under the Northern Basin, is of shallow marine and brackish-water origin. The richest brackish-water fauna is found in the silts and sands of the Telemaque member. Again, the most common species are *Miliammina telemaguensis* Saunders, n. sp., and *Arenoparrella mexicana* (Kornfeld), emend. Andersen, with, in addition, *Ammoastuta inepta* (Cushman and McCulloch) and occasional *Ammobaculites* spp., *Elphidium* spp., and *Rotalia beccarii* (Linné).

Brackish-water arenaceous faunas are found to alternate with slightly more marine faunas that are composed almost entirely of *Rotalia beccarii* (Linné) and *Elphidium*. In Dominion Oil Limited's Mahaica well no. 1, situated in the Northern Basin, cores at 5300 and 5600 feet have yielded a very rich brackish-water fauna that is more closely related to Recent faunas than is the case with other fossil assemblages. The following species are present:

- Arenoparrella mexicana* (Kornfeld), emend. Andersen
- Haplophragmoides manilaensis* Andersen
- Tiphotrecha comprimata* (Cushman and Bronnimann), emend. Saunders
- Haplophragmoides wilberti* Andersen?
- Miliammina petila* Saunders, n. sp.
- Ammoastuta inepta* (Cushman and McCulloch)
- Ammobaculites* spp.

The bulk of the fauna is composed of "floods" of *Arenoparrella mexicana* and *Haplophragmoides manilaensis*. Amongst Recent brackish-water faunas, that of the Carenage Swamp is remarkably similar to these faunas from Mahaica well no. 1.

Faunal evidence suggests that during the deposition of the Springvale formation, there were repeated alternations of shallow-water marine conditions and inshore swamp and estuarine conditions. During the former, the water was sometimes of normal salinity, when shell beds were deposited, and sometimes brackish, as in the present Gulf of Paria, when faunas of small calcareous foraminifera of the genera *Rotalia* and *Elphidium* lived. When the land stood relatively higher, arenaceous faunas, such as those found in the Telemaque member and in cores from the Mahaica well (mentioned above), dominated the mangrove swamps and extensive river estuaries that covered central Trinidad.

### Talparo formation

The general faunal aspect of this upper Miocene and Pliocene formation, although still brackish, suggests

slightly higher salinities, on the average, than those prevailing during deposition of the underlying Springvale formation. The proportion of *Ammobaculites* species and of calcareous genera, such as *Rotalia* and *Elphidium*, is higher in the younger formation.

### La Brea formation

The sands, silts, bedded lignites, and porcellanites of this upper Miocene and Pliocene formation usually seem to be devoid of foraminifera, although it is probable that brackish-water faunas did exist but that the tests were destroyed during fossilisation. On the Vessigny coast west of Point Fortin, Trinidad, one silt with plant remains has yielded a rich fauna composed entirely of *Miliammina telemaguensis* Saunders, n. sp.

During the Pleistocene, most deposits in Trinidad were laid down under fresh water and, up to the present time, no faunas, either thecamoebian or foraminiferal, have been found.

### SYSTEMATIC DESCRIPTIONS

#### Family REOPHACIDAE

Genus AMMOASTUTA Cushman and Bronnimann, emend. Bursch, 1952

*Ammoastuta inepta* (Cushman and McCulloch)  
Plate 1, figures 4-7

*Ammobaculites ineptus* CUSHMAN AND MCCULLOCH, 1939, Southern California, Univ., Publ., Allan Hancock Pacific Exped., vol. 6, no. 1, p. 89, pl. 7, fig. 6a-b.

*Ammoastuta salsa* CUSHMAN AND BRONNIMANN, 1948, Cushman Lab. Foram. Res., Contr., vol. 24, pt. 1, p. 17, pl. 3, figs. 14-16.

*Ammoastuta salsa* Cushman and Bronnimann, emend. BURSCH, 1952, Jour. Pal., vol. 26, no. 6, p. 922, pl. 132, figs. 5-6.

*Description:* Test bisymmetrical, subflabelliform with chambers in a curved uniserial sequence. Wall composed of fine sand grains set in cement; surface smooth. An inner chitinous layer is present. Proloculus and three to four juvenile chambers almost straight uniserial. The five to nine chambers of the adult stage are added in a curved uniserial sequence, the first chamber overlapping down one side of the series of juvenile chambers; adult chambers increasing rapidly in size as added, later ones embracing the basal portions of earlier adult chambers. Sutures distinct, flush with the surface in earlier chambers, somewhat depressed in later chambers. Main aperture a short transverse slit approximately in the centre of each chamber. Cribrate openings perforate the lower bulging end of the last-formed chamber, and are present, although concealed, in the earlier adult chambers.

**Dimensions:** Length of Recent hypotype (U.S.N.M. no. 5584) 0.41 mm.; greatest width 0.17 mm.; thickness 0.11 mm. Length of Recent hypotype (U.S.N.M. no. 5585) 0.48 mm.; greatest width 0.32 mm.; thickness 0.12 mm. Length of fossil hypotype (U.S.N.M. no. 5586) 0.48 mm.; greatest width 0.37 mm.; thickness approximately 0.08 mm. Length of fossil hypotype (U.S.N.M. no. 5587) 0.47 mm.; greatest width 0.24 mm. Amongst Recent specimens examined, the range of sizes observed is as follows: Length 0.32–0.48 mm.; greatest width 0.17–0.33 mm.; thickness averaging 0.09 mm.

**Localities and horizons:** The Recent hypotypes (U.S.N.M. nos. 5584 and 5585) are from Station no. 238, Ortoire River, east coast of Trinidad; the fossil hypotypes (U.S.N.M. nos. 5586 and 5587) are from sample K.R. 24434, Telemaque sand member of the Miocene Springvale formation, Springvale area, Central Range, Trinidad. In Recent sediments the species occurs widely in river estuaries and mangrove swamps around the coasts of Trinidad. It has been recorded in several samples from the Miocene Springvale formation and in one sample from the Pliocene Talparo formation of Trinidad, although in all cases it is rare.

**Remarks:** Examination of a specimen of *Ammonoastuta inepta* (Cushman and McCulloch) in the collection of the U. S. National Museum, Washington, has convinced the present author that *Ammonoastuta salsa* Cushman and Bronnimann is a junior synonym of this species. The variation in size and shape of specimens of "*Ammonoastuta salsa*" collected in Trinidad is considerable (see "**Dimensions**," above). A narrow specimen figured here (pl. 1, fig. 4) is almost exactly similar in shape and size to the specimen of *Ammonoastuta inepta* illustrated by Cushman and McCulloch (1939, pl. 7, fig. 6a–b).

Fossil representatives of the species are invariably badly distorted, because of the weakness of the wall structure. It is usual to find that all colour has been bleached out; this is characteristic of other fossil brackish-water forms collected from outcrops of the Miocene and Pliocene of Trinidad. It has not been possible to identify the cribrate apertures without question in any fossil examples of *Ammonoastuta inepta*, but this is not surprising in view of the state of preservation.

*Ammonoastuta inepta* is widely distributed in the Recent sediments of river estuaries and swamps. Its tolerance of variations in salinity is considerable, as it occurs from the highest parts of the tidal sections of the rivers almost to the open sea, and within and outside of mangrove swamps flanking the brackish Gulf of Paria. It is associated with such arenaceous species as *Trochammina salsa* (Cushman and Bronnimann), emend. Saunders, *Arenoparrella mexicana* (Kornfeld), emend. Andersen, *Tiphrotricha comprimata* (Cushman and Bronnimann), emend. Saunders, *Miliammina petila* Saunders, n. sp., and others. In fossil assemblages, when present at all, it is always rare. So far it has been found associated with floods of *Arenoparrella mexicana* (Kornfeld), emend.

Andersen, and *Miliammina telemaquensis* Saunders, n. sp. in the Miocene Springvale formation and in the Pliocene Talparo formation. Following Bursch (1952), the species has been placed provisionally in the Reophacidae.

### *Ammonoastuta alberdingi* (Bursch)

Plate 1, figure 8

*Praeammonoastuta alberdingi* BURSCH, 1952, Jour. Pal., vol. 26, no. 6, p. 917, pl. 132, figs. 1–4.

**Description:** Test bisymmetrical, subflabelliform with chambers in a curved uniserial sequence. Wall finely arenaceous. Proloculus and three to five juvenile chambers almost straight uniserial. Chambers of the adult stage added in a curved uniserial sequence, the first one overlapping down one side of the series of juvenile chambers; there are from five to ten adult chambers, increasing rapidly in size as added. Main aperture a transverse slit approximately in the centre of the terminal face of the last chamber. Cribrate openings may be seen to perforate the lower ends of the final adult chamber in somewhat better-preserved specimens, although in most cases all apertural details have been obliterated.

**Dimensions:** Length of figured hypotype (U.S.N.M. no. 5588) 0.33 mm.; greatest width 0.32 mm.; thickness approximately 0.08 mm. This is about the average size for specimens collected from this locality.

**Locality and horizon** The figured hypotype (U.S.N.M. no. 5588) is from a surface sample of Miocene(?) age collected in the Barbula Lots, Guárico State, Venezuela.

**Remarks:** In size, general shape, number of chambers, and wall structure, the specimens examined approach *Praeammonoastuta alberdingi* Bursch so closely that the author feels bound to place them in this species. All are poorly preserved, and in most forms the lower ends of the adult chambers are either badly crushed or have been lost altogether. However, at least two specimens show traces of cribrate openings at the bases of the chambers, and for this reason the present author places them in the genus *Ammonoastuta*. Examination of Dr. Bursch's type material in the U. S. National Museum, Washington, and of material from the Leon formation kindly supplied by Dr. Wolf Maync, shows that previously known specimens of this species are equally badly preserved, and that many of them likewise have the lower ends of the chambers broken off. In the present author's view, it is likely that cribrate apertures were present but that they have been lost in the majority of cases during fossilisation of the delicate tests. The author has received specimens of *Ammonoastuta caudriae* Petters from Dr. Petters. In the description of that species (Petters, 1954), cribrate apertures are said to be present, showing that they had already been developed in the Upper Eocene.

In the samples from the Miocene(?) of Barbula Lots, *Ammonoastuta alberdingi* is associated with *Arenoparrella mexicana* (Kornfeld), emend. Andersen, species of *Am-*



## BRACKISH-WATER FORAMINIFERA IN TRINIDAD

*mobaculites*, and species of *Miliammina*, suggesting inshore brackish-water conditions such as are found in the Miocene Springvale formation of Trinidad. It is possible that some of the specimens from the Tertiary of Trinidad that have been provisionally included in *Ammoastuta inepta* (Cushman and McCulloch) may belong instead to *Ammoastuta alberdingi*.

### Family LITUOLIDAE

#### Genus HAPLOPHRAGMOIDES Cushman, 1910

##### *Haplophragmoides manilaensis* Andersen

Plate 1, figures 1-3

*Haplophragmoides manilaensis* ANDERSEN, 1953, Cushman Found. Foram. Res., vol. 4, pt. 1, p. 22, pl. 4, fig. 8. - SAUNDERS, 1957, Smithsonian Inst., Misc. Coll., vol. 134, no. 5, p. 2, pl. 1, figs. 1-2.

**Description:** Test planispiral, completely or almost completely involute, with a lobate equatorial periphery. Axial periphery rounded. Wall composed of fine sand grains with little cement; surface slightly rough in Recent forms, smooth in fossil forms. Seven to ten chambers (usually eight) in the last whorl, increasing fairly rapidly in size. The terminal face of the last chamber may be flattened or slightly concave. Sutures straight, slightly depressed. Aperture interiomarginal and equatorial, a low arched slit surrounded by a narrow projecting lip.

**Dimensions:** Greatest diameter of Recent hypotype (U.S.N.M. no. 5581) 0.52 mm.; thickness 0.25 mm. Greatest diameter of fossil hypotype (U.S.N.M. no. 5582) 0.67 mm.; thickness approximately 0.08 mm. Greatest diameter of fossil hypotype (U.S.N.M. no. 5583) 0.71 mm.; thickness of last chamber 0.28 mm.

**Localities and horizons:** The Recent hypotype (U.S.N.M. no. 5581) is from sample J.S. 274, Carenage Swamp, west coast of Trinidad; the fossil hypotypes (U.S.N.M. nos. 5582 and 5583) are from the Miocene Springvale formation, in a core at 5305-5315 feet in Dominion Oil Limited's Mahaica well no. 1.

So far, sampling in Trinidad has revealed the presence of this species only in Recent deposits in Carenage Swamp and very sparsely in the Caroni River, on the west coast of Trinidad, and in the Miocene Springvale formation where the latter is penetrated by Mahaica well no. 1.

**Remarks:** The range in size of Recent examples of the species is considerable. All fossil specimens found so far have been severely distorted, but before crushing they would certainly have fitted into the size-range of the species as known from the Recent. A large Recent specimen of this species which is closely comparable with the fossil forms is illustrated by Saunders (1957, pl. 1, fig. 1a, b). The fossil forms show a slightly finer wall texture.

In the Carenage Swamp, on the west coast of Trinidad, *Haplophragmoides manilaensis* occurs in great numbers in association with *Haplophragmoides wilberti* Andersen, *Arenoparrella mexicana* (Kornfeld), emend. Andersen, *Siphotrochammina lobata* Saunders, and species of *Elphidium* and of *Rotalia*. Fossil occurrences of the species in Trinidad are so far known only in the Miocene Springvale formation, and there only from a core at 5305-5315 feet in Dominion Oil Limited's Mahaica well no. 1. The species occurs in floods, associated with great numbers of *Arenoparrella mexicana* (Kornfeld), emend. Andersen, and with *Miliammina telemaquensis* Saunders, n. sp., *Ammoastuta inepta* (Cushman and McCulloch), and species of *Ammobaculites*. A close parallel can be drawn between the faunas of the Mahaica well and of the Recent Carenage Swamp, and from this analogy it is inferred that the former faunas reflect a swamp environment rather than an estuarine one. Heretofore, *Haplophragmoides manilaensis* had been known only from the Recent.

### Family TROCHAMMINIDAE

#### Genus TIPHOTROCHA Saunders, 1957

##### *Tiphotrocha comprimata*

(Cushman and Bronnimann), emend. Saunders

Plate 2, figures 1-4

*Trochammina comprimata* CUSHMAN AND BRONNIMANN, 1948, Cushman Lab. Foram. Res., Contr., vol. 24, pt. 2, p. 41, pl. 8, figs. 1-3.

*Tiphotrocha comprimata* (Cushman and Bronnimann), emend. SAUNDERS, 1957, Smithsonian Inst., Misc. Coll., vol. 134, no. 5, p. 11, pl. 4, figs. 1-4.

**Description:** Test trochospiral, compressed, with an irregularly lobate equatorial periphery; spiral side slightly convex, umbilical side concave. Axial periphery rounded, subangular or angular in very compressed Recent forms and in distorted fossil forms. Wall composed of fine sand grains with little cement; surface smooth. Four to six chambers (usually five) in the last whorl, often rather irregular in shape and considerably elongated in the direction of coiling, with somewhat inflated lobes projecting into the umbilicus. In large specimens the last chambers are inflated and roughly T-shaped in umbilical aspect. Sutures slightly depressed, curved. Apertures in the last whorl situated at the ends of the chamber prolongations into the umbilicus and covered by shelf-like lips. When the last chamber is highly developed, the lip on its umbilical prolongation may obscure the earlier apertures. Many specimens show a fusion of the umbilical prolongations of the chambers, completely covering the umbilicus (pl. 2, figs. 2-3).

**Dimensions:** Greatest diameter of Recent hypotype (U.S.N.M. no. 5594) 0.52 mm.; thickness 0.15 mm. Greatest diameter of Recent hypotype (U.S.N.M. no. 5595) 0.53 mm.; thickness 0.12 mm. Greatest diameter of fossil hypotype (U.S.N.M. no. 5596) 0.55 mm.;

thickness 0.12 mm. Greatest diameter of fossil hypotype (U.S.N.M. no. 5597) 0.37 mm.; thickness 0.08 mm.

**Localities and horizons:** The Recent hypotypes (U.S.N.M. nos. 5594 and 5595) are from Station no. 262, Ortoire River, east coast of Trinidad; the fossil hypotype (U.S.N.M. no. 5596) is from the Miocene Springvale formation, in a core at 5622–5625 feet in Dominion Oil Limited's Mahaica no. 1 well; the fossil hypotype (U.S.N.M. no. 5597) is from the same formation and well, in a core at 5305–5315 feet. *Tiphotrecha comprimata* is widely distributed in Recent estuarine sediments in Trinidad, but in fossil sediments it has been found only in the Miocene Springvale formation.

**Remarks:** All fossil examples of the species found so far are badly deformed; in most instances the apertural details have been obscured. However, the species is distinguishable by the characteristic shape of the chambers in umbilical aspect, and sometimes by the presence of a "plate" across the umbilicus formed by the coalescence of the umbilical projections of the chambers of the last whorl (pl. 2, fig. 3). In fossil assemblages, *Tiphotrecha comprimata* has always been found occurring in small numbers with floods of *Arenoparrella mexicana* (Kornfeld), emend. Andersen. Heretofore, *Tiphotrecha comprimata* had been known only from the Recent.

Genus *ARENOPARRELLA* Andersen, emend.  
Andersen, 1951

*Arenoparrella mexicana* (Kornfeld), emend. Andersen  
Plate 2, figures 5–7

*Trochammina inflata* (Montagu) var. *mexicana* KORNFIELD, 1931, Stanford Univ., Dept. Geol., Contr., vol. 1, p. 86, pl. 13, fig. 5a–c.

*Arenoparrella mexicana* (Kornfeld). – ANDERSEN, 1951, Jour. Pal., vol. 25, no. 1, p. 31, text-fig. 1a–c. – ANDERSEN, 1951, Cushman Found. Foram. Res., Contr., vol. 2, pt. 3, p. 96, pl. 11, fig. 4a–c.

*Arenoparrella mexicana* (Kornfeld), emend. Andersen. – SAUNDERS, 1957, Smithsonian Inst., Misc. Coll., vol. 134, no. 5, p. 12, pl. 4, fig. 5a–c.

**Description:** Test trochospiral, involute on the umbilical side, with a smooth or very slightly lobate equatorial periphery; spiral side slightly convex, umbilical side with a small, depressed, closed umbilicus; axial periphery rounded in undistorted specimens. Wall composed of fine sand grains set in abundant cement; surface smooth, often polished in Recent specimens. Chambers slightly inflated on the spiral side, more strongly so on the umbilical side; five, six or more (rarely seven) chambers in the last whorl, increasing in size regularly and gradually. Sutures distinct, almost flush with the surface on the spiral side, depressed on the umbilical side, straight or slightly curved. Primary aperture a narrow slit in the terminal face, commencing in an interiomarginal equatorial position and with its long axis roughly parallel to the spiral surface. Supplementary apertures up to eleven or twelve cribrate openings at the apex of the chamber.

**Dimensions:** Greatest diameter of Recent hypotype (U.S.N.M. no. 5598) 0.49 mm.; thickness 0.17 mm. Greatest diameter of fossil hypotype (U.S.N.M. no. 5599) 0.37 mm.; thickness 0.11 mm. Greatest diameter of fossil hypotype (U.S.N.M. no. 5600) 0.41 mm.; thickness approximately 0.08 mm. Both fossil hypotypes are badly distorted.

**Localities and horizons:** The Recent hypotype (U.S.N.M. no. 5598) is from Station no. 238, Ortoire River, east coast of Trinidad; the fossil hypotypes (U.S.N.M. nos. 5599 and 5600) are from sample S.L. 6351, Telemaque sand member of the Miocene Springvale formation, Union Estate, Central Range, Trinidad.

*Arenoparrella mexicana* is widely distributed in the Recent swamps and river estuaries of Trinidad. In fossil sediments it has been found occurring plentifully in scattered samples from the Pliocene Talparo formation and the Miocene Springvale formation, Mayaro clay, Morne l'Enfer formation, and Cruse formation. In the last, it occurs only in slipped blocks of highly lignitic silt carried into a deep-water environment.

**Remarks:** The fossil specimens are invariably badly distorted, and for this reason the cribrate apertures are nearly always obscured; in many cases the main aperture is likewise not visible. Bleaching of the specimens, due to weathering of surface samples, is usual in this species, as in all brackish-water forms found in Miocene and Pliocene deposits.

In Recent samples, *Arenoparrella mexicana* is associated with *Miliammina petila* Saunders, n. sp., *Trochammina salsa* (Cushman and Bronnimann), emend. Saunders, and other forms in the river estuaries, and with floods of *Haplophragmoides manilaensis* Andersen in the Carenage Swamp. In the Miocene and Pliocene brackish-water sediments, *Arenoparrella mexicana* and *Miliammina telemaquensis* Saunders, n. sp., are by far the most common species present. They may be found associated in equal numbers although usually floods of one or the other predominate.

Heretofore, *Arenoparrella mexicana* had been described only from the Recent, although it had almost certainly been recorded from brackish-water sediments of Venezuela under the name *Haplophragmoides* sp. (e.g., Hedberg, 1934).

## Family SILICINIDAE

Genus *MILIAMMINA* Heron-Allen and Earland,  
emend. Loeblich and Tappan, 1955

*Miliammina* cf. *fusca* (H. B. Brady)  
Plate 1, figure 9

*Quinqueloculina fusca* H. B. BRADY, 1870, Ann. Mag. Nat. Hist., ser. 4, vol. 6, p. 286, pl. 11, figs. 2a–c, 3.

**Description:** Chambers arranged in a quinqueloculine series. Wall siliceous, composed of small quartz grains with almost no cement; surface rough. Aperture termi-

## BRACKISH-WATER FORAMINIFERA IN TRINIDAD

nal, with or without a narrow tooth extending from the inner wall of the chamber.

**Dimensions:** Length of figured specimen (U.S.N.M. no. 5589) 0.33 mm.; width 0.21 mm.; thickness 0.13 mm.

**Localities and horizons:** The figured specimen (U.S.N.M. no. 5589) is from sample J.S. 119, Maracas Bay River, north coast of Trinidad. *Miliammina* cf. *fusca* occurs in great numbers throughout the brackish-water section of the Maracas Bay River; at the seaward end of its range, it is accompanied by *Miliammina petila* Saunders, n. sp., *Trochammina salsa* (Cushman and Bronnimann), emend. Saunders, *Arenoparrella mexicana* (Kornfeld), emend. Andersen, and floods of *Trochammina irregularis* Cushman and Bronnimann, emend. Saunders. In other rivers and swamps in Trinidad where sampling has been carried out, it is either absent or, when present, does not occur in such numbers as in the Maracas Bay River. *Miliammina* cf. *fusca* has not been identified with certainty in fossil brackish-water assemblages, although the poor preservation of much of this material makes it quite possible that this species has been overlooked.

**Remarks:** This form has been identified by many authors from samples taken along the coasts of America, and it has usually been referred to *Miliammina fusca* or as *Miliammina* cf. *fusca*. Examination of the hypotype collection of *Miliammina fusca* in the U. S. National Museum, Washington, shows that unfortunately a number of other *Miliammina* species have been included under the same name. As Brady's types of *Quinqueloculina fusca* appear to have been lost, it is impossible to be sure what his species should include. The illustrations, descriptions, and sizes given by Brady suggest that the Trinidad specimens here referred to as *Miliammina* cf. *fusca* are close to the types of Brady's species. Brady made no mention of the presence of a tooth, but one is not invariably present in the specimens from Trinidad. In the present writer's opinion, it is best to use the name *Miliammina* cf. *fusca* for the Recent form here illustrated in plate 1, figure 9.

The species differs from *Miliammina petila* Saunders, n. sp., in its greater width and thickness relative to the length, and in its coarser wall with much less cement; a tooth is not invariably present, but when it is present, it is less broad and flat than that of *Miliammina petila*. *Miliammina* cf. *fusca* and *Miliammina petila* Saunders, n. sp., are found together in some Recent brackish-water localities in Trinidad, for example, in the Maracas Bay River, but *Miliammina petila* has much wider distribution and is present in some rivers where *Miliammina* cf. *fusca* has not been found, for example, throughout the brackish section of the Ortoire River.

### *Miliammina petila* Saunders, sp. nov.

Plate 1, figures 10-11

**Description:** Test small, width and thickness approximately equal, both being less than half the length. Chambers arranged in a quinqueloculine series. Wall

siliceous, composed of minute quartz grains in a large amount of siliceous cement; surface smooth. Aperture terminal, almost closed by a broad, flat tooth formed by an infolding of the lip at the inner edge of the last chamber.

**Dimensions:** Length of holotype (U.S.N.M. no. 5590) 0.29 mm.; width 0.13 mm.; thickness 0.11 mm. Length of figured hypotype (U.S.N.M. no. 5591) 0.39 mm.; width 0.19 mm.; thickness 0.13 mm.

**Localities and horizons:** The holotype (U.S.N.M. no. 5590) is from Station no. 236, Ortoire River, east coast of Trinidad; the fossil hypotype (U.S.N.M. no. 5591) is from the Miocene Springvale formation, in a core at 5305-5315 feet in Dominion Oil Limited's Mahaica well no. 1.

In Recent brackish-water sediments, *Miliammina petila* is one of the most widespread of the arenaceous foraminifera, occurring as it does in swamps and river estuaries. It shows a high degree of tolerance of variations in salinity, as is shown by its broad distribution in the Ortoire River (see text-fig. 2). In fossil sediments the species has been identified definitely in the Miocene Springvale formation in Mahaica well no. 1. At other localities, preservation of material makes it difficult to identify many of the specimens of *Miliammina* with certainty.

**Remarks:** *Miliammina petila*, n. sp., differs from *Miliammina* cf. *fusca* (H. B. Brady) in its more elongate test, in its finer wall structure, due to smaller grains and more cement, and in its much broader tooth, which almost fills the aperture. It differs from *Miliammina telemaquensis* Saunders, n. sp., in its much smaller size, in its more elongate shape, and in its finer wall structure.

### *Miliammina telemaquensis* Saunders, sp. nov.

Plate 1, figures 12-13

**Description:** Chambers arranged in a quinqueloculine series. Wall siliceous, composed of small quartz grains with a variable amount of siliceous cement; surface usually rough, depending on the amount of cement present. Aperture terminal, with a broad flattened tooth.

**Dimensions:** Length of holotype (U.S.N.M. no. 5592) 0.63 mm.; width 0.32 mm.; thickness 0.16 mm. Length of figured paratype (U.S.N.M. no. 5593) 0.57 mm.; width 0.44 mm. The figures for the width and thickness of these two specimens are of little significance, as both have been strongly deformed.

**Localities and horizons:** Holotype (U.S.N.M. no. 5592) and paratype (U.S.N.M. no. 5593) from sample R.M. 12114, on the road to Mayaro well no. 2, Mayaro area, east coast of Trinidad, in the Miocene Mayaro clay. The species has not been found in Recent sediments, but is the most widespread fossil arenaceous foraminifer in the brackish-water deposits of the Miocene and Pliocene in Trinidad.

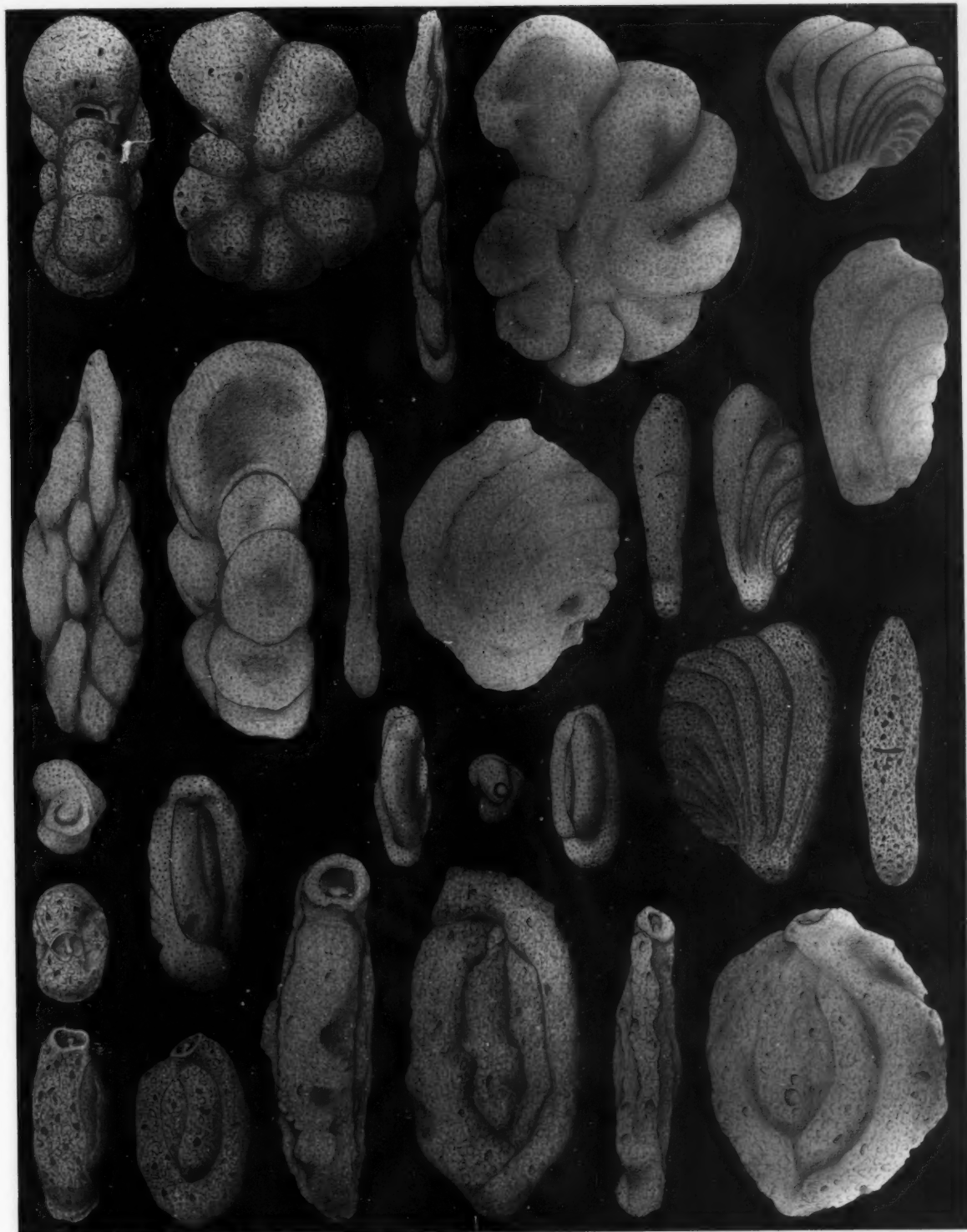
# SAUNDERS

## PLATE 1

All figures approximately  $\times 105$ .

- 1 *Haplophragmoides manilaensis* Andersen  
a, side view of hypotype (U.S.N.M. no. 5581); b, apertural view showing an aperture that is more highly arched than is typical in the species. Sample J.S. 274, Carenage Swamp, west coast of Trinidad; Recent.
- 2 *Haplophragmoides manilaensis* Andersen  
a, side view of hypotype (U.S.N.M. no. 5582); b, apertural view; this specimen is strongly compressed laterally. Dominion Oil Limited's Mahaica well no. 1, core at 5305-5315 feet; Springvale formation, Miocene.
- 3 *Haplophragmoides manilaensis* Andersen  
a, side view of hypotype (U.S.N.M. no. 5583); b, apertural view; this specimen is strongly compressed. Same sample as in figure 2; Springvale formation, Miocene.
- 4 *Ammoastuta inepta* (Cushman and McCulloch)  
a, side view of hypotype (U.S.N.M. no. 5584); b, apertural view; a small, rather narrow specimen. Station no. 238, Ortoire River, east coast of Trinidad; Recent.
- 5 *Ammoastuta inepta* (Cushman and McCulloch)  
a, side view of hypotype (U.S.N.M. no. 5585); b, apertural view. Station no. 238, Ortoire River, east coast of Trinidad; Recent.
- 6 *Ammoastuta inepta* (Cushman and McCulloch)  
a, side view of hypotype (U.S.N.M. no. 5586); b, apertural view; a strongly compressed and bleached fossil specimen with apertures obscured. Sample K.R. 24434, Springvale area, Central Range, Trinidad; Telemaque sand member, Springvale formation, Miocene.
- 7 *Ammoastuta inepta* (Cushman and McCulloch)  
a, side view of hypotype (U.S.N.M. no. 5587); another deformed and bleached fossil specimen. Same sample as in figure 6; Telemaque sand member, Springvale formation, Miocene.
- 8 *Ammoastuta alberdingi* (Bursch)  
Side view of hypotype (U.S.N.M. no. 5588); a small, rather compressed specimen drawn in a mixture of reflected and transmitted light; specimen badly preserved but showing traces of cribrate apertures at the base of the last chamber. Sample P. 49, Barbula Lots, Guárico State, Venezuela; Miocene.
- 9 *Miliammina cf. fusca* (H. B. Brady)  
a, side view of figured specimen (U.S.N.M. no. 5589); b, edge view; c, apertural view. Sample J.S. 119, Maracas Bay River, north coast of Trinidad; Recent.
- 10 *Miliammina petila* Saunders, n. sp.  
a, side view of holotype (U.S.N.M. no. 5590); b, edge view; c, apertural view, showing the characteristic large, flattened tooth. Station no. 236, Ortoire River, east coast of Trinidad; Recent.
- 11 *Miliammina petila* Saunders, n. sp.  
a, side view of hypotype (U.S.N.M. no. 5591); b, apertural view. Dominion Oil Limited's Mahaica well no. 1, core at 5305-5315 feet; Springvale formation, Miocene.
- 12 *Miliammina telemaquensis* Saunders, n. sp.  
a, side view of holotype (U.S.N.M. no. 5592); b, apertural view, showing the flattened tooth; a crushed specimen that shows the apertural features better than is usual in the Trinidad material of the species. Sample R.M. 12114, road to Mayaro well no. 2, Mayaro area, east coast of Trinidad; Mayaro clay, Miocene.
- 13 *Miliammina telemaquensis* Saunders, n. sp.  
a, side view of paratype (U.S.N.M. no. 5593); b, edge view. Same sample as in figure 12; Mayaro clay, Miocene.







BRACKISH-WATER FORAMINIFERA IN TRINIDAD

PLATE 2

All figures approximately  $\times 105$ .

- 1 *Tiphotrocha comprimata* (Cushman and Bronnimann), emend. Saunders  
a, spiral view of hypotype (U.S.N.M. no. 5594); b, umbilical view, showing the chambers of the last whorl opening separately into the umbilicus; c, edge view. Station no. 262, Ortoire River, east coast of Trinidad; Recent.
- 2 *Tiphotrocha comprimata* (Cushman and Bronnimann), emend. Saunders  
Umbilical view of hypotype (U.S.N.M. no. 5595), showing the umbilicus obscured by the fusion of lobes from the chambers of the last whorl. Station no. 262, Ortoire River, east coast of Trinidad; Recent.
- 3 *Tiphotrocha comprimata* (Cushman and Bronnimann), emend. Saunders  
a, spiral view of hypotype (U.S.N.M. no. 5596); b, umbilical view; a distorted specimen showing a "plate" of sand grains covering the umbilicus, a condition found in both Recent and fossil specimens. Dominion Oil Limited's Mahaica well no. 1, core at 5622-5625 feet; Springvale formation, Miocene.
- 4 *Tiphotrocha comprimata* (Cushman and Bronnimann), emend. Saunders.  
a, spiral view of hypotype (U.S.N.M. no. 5597); b, umbilical view, showing the last two chambers opening separately into the umbilicus; c, edge view; a small specimen in which the chambers of the last whorl do not have pronounced umbilical lobes; this type of small test occurs amongst both Recent and fossil representatives of the species. Dominion Oil Limited's Mahaica well no. 1, core at 5305-5315 feet; Springvale formation, Miocene.
- 5 *Arenoparrella mexicana* (Kornfeld), emend. Andersen  
a, spiral view of hypotype (U.S.N.M. no. 5598); b, umbilical view; c, edge view. Station no. 238, Ortoire River, east coast of Trinidad; Recent.
- 6 *Arenoparrella mexicana* (Kornfeld), emend. Andersen  
a, spiral view of hypotype (U.S.N.M. no. 5599), showing three cribrate openings at the apex of the last chamber; b, umbilical view; c, edge view; a badly compressed, bleached specimen. Sample S.L. 6351, Union Estate, Central Range, Trinidad; Springvale formation, Miocene.
- 7 *Arenoparrella mexicana* (Kornfeld), emend. Andersen  
Umbilical view of hypotype (U.S.N.M. no. 5600); a compressed, bleached specimen but one that shows the main aperture of the last chamber. Same sample as in figure 6; Springvale formation, Miocene.

*Remarks:* Up to the present time, all specimens of this species found have been badly flattened. Because of this fact, it is difficult to ascertain the nature of the apertural tooth, but it is considered to be an infolding of the lip of the last chamber.

*Miliammina telemaquensis* differs from *Miliammina* cf. *fusca* (H. B. Brady) in its considerably larger size and in its more flattened apertural tooth; *Miliammina telemaquensis* has not been found in Recent samples, whereas *Miliammina* cf. *fusca* has so far not been recognised in fossil assemblages in Trinidad. *Miliammina telemaquensis* differs from *Miliammina petila* Saunders, n. sp., in its considerably larger size, in its greater width relative to length, and in its coarser wall.

In the collections of the U.S. National Museum, Washington, there is a specimen collected by Dr. Hedberg from the "Miocene" of the Maracaibo Basin, western Venezuela, and called by him *Quinqueloculina fusca* Brady; this is undoubtedly a specimen of *Miliammina telemaquensis*. It seems likely that this species has wide distribution in the Tertiary brackish-water sediment of Venezuela. In Trinidad, *Miliammina telemaquensis* occurs in floods in the Telemaque member of the Springvale formation and in the Mayaro clay, both of Miocene age; when other foraminifera are present, *Arenoparrella mexicana* (Kornfeld), emend. Andersen, is by far the most common. In the Miocene lower Cruse formation at Quinam, on the south coast of Trinidad, boulders of lignitic silt, carrying a rich fauna of *Miliammina telemaquensis*, are found in beds that are thought to be of deeper-water origin (see the discussion of the Cruse formation, above). It is suggested that sediments carrying floods of *Miliammina telemaquensis* were laid down under swamp conditions rather than under river-estuarine conditions.

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ABSTRACT: *Holothurian sclerites from the Permian Florena shale are assigned to four species, belonging to four different genera. Two of the genera and three of the species are new.*

## Holothurian sclerites from the Florena shale (Permian) of Kansas

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### INTRODUCTION

For a number of years the authors of this paper have been engaged in a detailed stratigraphic, petrographic, and paleontological analysis of the Florena shale member of the Beattie limestone, a lithologically variable but laterally persistent unit in the mid-continent Wolfcampian. In the course of this work, well preserved holothurian sclerites were found in samples from three localities in northern Kansas. Although a systematic search for holothurian sclerites has not been made to date at other localities, it is highly probable that these fossils are widely distributed in the Florena. Indeed, the general scarcity of published reports of fossil holothurians is almost surely due to the lack of attention this group has received rather than to any inherent rarity. In this connection it is pertinent to note that Hattin (1957) has reported holothurians from the Schroyer limestone and the Speiser, Havensville, and Wymore shales of the Kansas Lower Permian. For an excellent summary of holothurian paleontology, the reader is referred to Frizzell and Exline (1955).

The material described in this paper was collected as part of a project sponsored by the Geological Society of America and the State Geological Survey of Kansas. Catalog numbers cited in the explanation of Plate 1 refer to the Columbia University paleontology collections.

### LIST OF LOCALITIES

*Locality 1:* Roadcut 4 miles southeast of Manhattan, NW $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 34, T. 10 S., R. 8 E., Riley County, Kansas.

*Locality 6:* Roadcut in the NW $\frac{1}{4}$ NE $\frac{1}{4}$  sec. 6, T. 6 S., R. 13 E., Jackson County, Kansas.

*Locality 10:* Railroad cut in the NW $\frac{1}{4}$ SE $\frac{1}{4}$  sec. 36, T. 16 S., R. 9 E., Morris County, Kansas.

### SYSTEMATIC DESCRIPTIONS

Phylum ECHINODERMATA

Class HOLOTHUROIDEA

Family THEELIIDAE Frizzell and Exline, 1955

Genus *Microantyx* Kornicker and Imbrie, new genus

*Type species: Microantyx permiana* Kornicker and Imbrie, n. sp.

*Diagnosis:* Sclerites in the form of wheels with short spokes; raised central hub and peripheral rim on lower side, and four depressions in central portion of upper side.

*Comparisons:* *Microantyx* differs from *Protocaudina* in having a central hub on the lower side. It differs from *Paleochiridota* in having four depressions in the central portion of the upper side.

*Remarks* A paratype of this species was examined by Frizzell and Exline, who concluded that this genus may have been derived from *Protocaudina* by the addition of a simple hub, and may be "... an end member of the typical *Protocaudina* lineage, which originated (as far as we yet know) in the Devonian" (personal communication, 1956).

*Range:* Permian.

**Microantyx permiana** Kornicker and Imbrie,  
new species

Plate 1, figures 1-6

**Description:** Sclerite in the form of a wheel with ten spokes; outline nearly circular; interspoke spaces low, and triangular in shape; central part of upper side with four central depressions; central depressions subtriangular; lower surface with raised rim and prominent central hub. Diameter 0.17-0.27 mm.; average diameter 0.23 mm.

**Comparisons:** *Microantyx permiana* is the only known species of this genus.

**Occurrence:** Type material was collected from the Florena shale at locality 10.

Family STICHOPITIDAE Frizzell and Exline, 1955

Genus UNCINULINA Terquem, 1862

**Uncinulina lunata** Kornicker and Imbrie, new species  
Plate 1, figure 7

**Description:** Sclerite in the form of a curved rod with ends bent sharply at an angle of about 85°; one end of the rod tapering to a point, the other end flaring; flared end of holotype apparently broken. Length of holotype 0.53 mm.; average diameter of rod 0.09 mm.

**Comparisons:** *Uncinulina lunata* differs from *Uncinulina angulata* Frizzell and Exline and from *Uncinulina arcuata* (Deflandre-Rigaud) in having a straight central portion. It differs from *Uncinulina polymorpha* Terquem and from *Uncinulina terquemi* Frizzell and Exline in that the end portions form a slightly obtuse angle with the central part of the rod. *Uncinulina lunata* is smaller than all other known species of this genus.

**Occurrence:** Type material was collected from the Florena shale at locality 10.

**Genus Parvispina** Kornicker and Imbrie, new genus

*Stichopites* Deflandre-Rigaud, emend. FRIZZELL AND EXLINE, 1955 (in part), Missouri, Univ., School Mines and Met., Bull., Tech. Ser., no. 89, p. 60.

**Type species:** *Stichopites spinosus* Frizzell and Exline, 1955.

**Diagnosis:** Sclerite in the form of a straight tapering rod with spines.

**Comparisons:** *Parvispina* differs from other rod-like sclerites in possessing spines.

**Remarks:** *Stichopites mortenseni*, the only species now remaining in *Stichopites* as that genus is here construed, differs from species assigned to *Parvispina* in lacking spines and in possessing a distinct curvature. In the judgment of the authors, these differences are striking enough to warrant the erection of a new genus.

**Range:** Species of this genus have been found to date in Mississippian and Permian strata.

**Parvispina harpago** Kornicker and Imbrie, new species  
Plate 1, figures 8-10

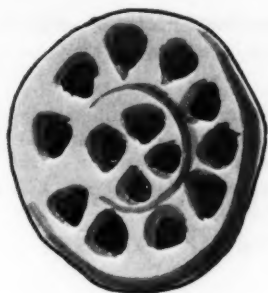
**Description:** Sclerite in the form of a tapering rod with unequal, slightly curved spines arranged in two mutually perpendicular planes passing through the axis. Length of a broken specimen 0.63 mm.; maximum width, including spines, 0.67 mm.; maximum spine projection 0.27 mm.

**Comparisons:** *Parvispina harpago* differs from *Parvispina spinosa* (Frizzell and Exline) in having spines that are more widely spaced and arranged in quadrate fashion.

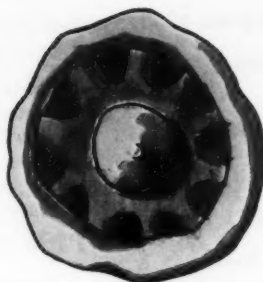
**Occurrence:** Type material was collected from the Florena shale at locality 1.

## PLATE 1

- 1-3 *Microantyx permiana* Kornicker and Imbrie, n. gen., n. sp.  
Holotype, CU no. 28,620,  $\times 170$ : 1, top view; 2, bottom view; 3, side view.
- 4-6 *Microantyx permiana* Kornicker and Imbrie, n. gen., n. sp.  
CU no. 28,621,  $\times 160$ : 4, top view; 5, bottom view (hub of specimen broken?); 6, side view.
- 7 *Uncinulina lunata* Kornicker and Imbrie, n. sp.  
Holotype, CU no. 28,622,  $\times 55$ .
- 8-10 *Parvispina harpago* Kornicker and Imbrie, n. gen., n. sp.  
Holotype, CU no. 28,623,  $\times 55$ : 8, side view; 9, bottom view; 10, top view.
- 11 *Achistrum brownwoodensis* (Croneis)  
CU no. 28,624,  $\times 45$ .
- 12-13 *Holothuroidea*(?) *incertae sedis*  
12, CU no. 28,625,  $\times 120$ ; 13, CU no. 28,626,  $\times 150$ .



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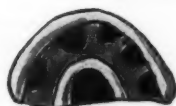
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Family ACHISTRIDAE Frizzell and Exline, 1955

Genus ACHISTRUM Etheridge, emend.

Frizzell and Exline, 1955

**Achistrum brownwoodensis** (Croneis)

Plate 1, figure 11

*Ancistrum brownwoodensis* CRONEIS, 1932, in CRONEIS AND McCORMACK, Jour., Pal., vol. 6, p. 143, pl. 21, figs. 3-8, 19-22, 29, 39.

*Achistrum brownwoodensis* (Croneis).—DEFLANDRE-RIGAUD, 1952, Monaco, Inst. Océanogr., Bull., no. 1012, p. 8.

**Description:** Sclerite in the form of a fish-hook without a barbed tip; shank straight; eye inclined slightly in the direction of hook projection. Eye-hole diameter smaller than diameter of shank.

**Comparisons:** This species differs from *Achistrum permianum* (Spandel) in having a straighter shank and inclined eye.

**Occurrence:** The occurrence of this species in the Florena shale previously reported by Kornicker (1954) was based on a single complete sclerite from locality 1. Twelve additional specimens (not complete) have since been obtained from locality 10.

**Holothuroidea(?) incertae sedis**

Plate 1, figures 12-13

Croneis and McCormack (1932, pl. 21, figs. 10, 13) illustrate fragments tentatively identified as holothurian fronds from the Chester sediments of Illinois. Serrated fragments of similar appearance occur in the Florena shale at locality 10 (pl. 1, figs. 12-13). Their actual affinity remains in doubt.

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ABSTRACT: The genus *Cuneolina* is represented in the lowermost Cretaceous of southwestern France by *Cuneolina hensoni* n. sp., an interesting zonal marker for para-reefal (Urgonian) facies.

## Cuneolina hensoni, a new lowermost Cretaceous marker in southwestern France

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### INTRODUCTION

During a systematic study of oil-field sequences of Lower Cretaceous age, the attention of the writer was attracted by various sections which seemed to belong to a species of *Cuneolina*. The sediments being very hard, it was impossible to obtain free specimens, and assembling enough random sections to obtain a good idea of the species required considerable time, as the species is not very abundant and is often represented by fragmentary specimens. When a sufficient amount of data had been accumulated, however, no doubt remained concerning the generic identification of the specimens, which are typical *Cuneolinas*. The range of the species, as it is given below, was carefully checked, and this appears to be the oldest record of this genus in the geologic time-scale.

### PREVIOUS LOWER CRETACEOUS RECORDS OF CUNEOLINA

The genus *Cuneolina* was recorded very doubtfully from the lowermost Cretaceous (Valanginian) of Provence by J. Pfender (1938, pl. 15, fig. 6), but Pfender's specimen is not a *Cuneolina*. It is more probably *Coskinolinoides texanus* Keijzer. One year later, the same author (Pfender, 1939) revised her opinion, stating: "On peut conclure que la trouvaille de *Cuneolina* dans le Crétacé supérieur équivaut à celle des Nummulites dans les terrains nummulitiques."

Schlumberger in 1883 noted the presence of "une petite espèce assez mal conservée très semblable comme forme à *Cuneolina pavonia* d'Orb., dans la couche à *Orbitolina lenticulata* Lmk. de l'Aptien de Bellegarde"; but this species has never been studied and described. Other records from the Albo-Aptian include a doubtful mention of *Cuneolina* in the Levant by Dubertret in 1937, an occurrence in Iraq reported

by Henson (1948), and one in the lower Albian of central Texas reported by Stead (1951), where it is associated with *Dictyoconus walnutensis* Carsey, *Coskinolinoides texanus* Keijzer, and *Nummuloculina*.

Mrs. Esther Applin, of the United States Geological Survey, kindly provided the writer with lowermost Cretaceous forms somewhat related to *Cuneolina*. These forms, however, are smaller and more acute than the French species, and Mrs. Applin states: "The form is narrowly cone-shaped, with a few specimens showing a tendency to flare slightly near the terminal end, which may also be somewhat compressed. All transverse sections, normal to the axis, also indicate the cone-shaped form of the fossil. No sections indicating compression of the lateral chambers, or flabelliform mature forms, have been found" (personal communication, January 25, 1957). The lack of compression of the test suggests to the writer that the American form probably belongs, not to *Cuneolina*, but to a closely related genus.

### DESCRIPTION OF THE SEQUENCE

The age of the sequence in which *Cuneolina hensoni* is found was very controversial until the Esso R.E.P. wildcat of Mano no. 1 disclosed the existence of the lowermost Cretaceous in western Aquitaine. It was believed by former authors that these beds were lacking in this area and that the Aptian was directly transgressive on the Jurassic. Actually, the sequence seems to be nearly complete, but the lack of diagnostic macrofauna and the shallow-water nature of the deposits had prevented an earlier recognition of this fact. Since that discovery, the lowermost Cretaceous has been recognized in the same facies over

a large area, in numerous wildcats, and it constitutes the most important oil reservoir of the area at the present time.

Beginning at the top, the sequence is composed first of interbedded fine crystalline limestone and dark limy shales. This formation, called SS8, is the lowest horizon of the Cretaceous to be dated by ammonites. Its fauna is characterized by *Deshayesites* ex gr. *deshayesi* (Leymerie) and *Dufrenoyia dufrenoyi* (d'Orbigny), which are typically of middle Aptian age. The underlying formation, R. 1, is an argillaceous limestone with abundant *Orbitolina*. This formation also contains some *Choffatella decipiens* Schlumberger and *Neotrocholina burgeri* (Emberger), with scarce *Pseudocyclammina*. Formation R.2 is composed of sandy limestones, coquinoid limestone, sandy shales, and breccia. The microfauna is scarce as a result of unfavorable sedimentation; there are rare specimens of *Orbitolina*, *Choffatella decipiens*, and smaller Lituolidae. Subcontinental conditions are locally marked by charophyte oögonia and brackish-water ostracodes. This formation is unconformable upon the next older one, and is most probably of lower Aptian or Barremian age.

Formation R.3-4 is represented by dense, finely crystalline, locally dolomitized limestone. Debris of calcareous algae, including Dasycladaceae, Codiaceae and Gymnocodiaceae, is abundant, together with numerous *Neotrocholina burgeri* and *Choffatella* ex gr. *decipiens*. Transition forms between *Dictyoconus* and *Orbitolina* are also present, but no typical *Orbitolina* has ever been found in this formation, although conditions seem to have been highly favorable to the development of this genus. This fact seems to indicate that *Orbitolina* had not yet appeared at that time, suggesting that these beds are of pre-Aptian-Barremian age.

The lowest formation of the Cretaceous is of a different type, and is separated from the overlying formation R.3-4 by a minor unconformity. It is called formation R.5-6, and is composed of a calcarenite which is very rich in microfauna. Pebbles of limestone are embedded in a calcite matrix and are often dolomitized. The microfauna consists of

numerous Miliolidae, including *Nautiloculina*, and frequent Valvulinidae, Textulariidae, *Neotrocholina burgeri*, and *Choffatella* ex gr. *decipiens*, together with Dasycladaceae and Codiaceae. A new species of larger foraminifera, *Cuneolina hensoni*, is typical of and restricted to this zone. It is described below and illustrated by the accompanying photographs.

Formation R.5-6 overlies a thin formation (R.7) of varicolored, often greenish lagoonal-lacustrine clays, which contain ostracodes (*Clavator reidi*) and charophytes (*Atopochara*). This fauna is indicative of the Cretaceous-Jurassic transition, of Purbeckian age. The clays of formation R.7 are underlain by a microcrystalline limestone devoid of any of the typical Cretaceous forms and containing *Spirocyclina infravalanginiensis* Schlumberger and *Favreina cuvillieri* Bronnimann, of Portlandian age.

#### AGE OF THE SEQUENCE

From these data it is evident that the *Cuneolina hensoni* zone, R.5-6, is pre-Aptian-Barremian and post-Purbeckian, both ages being established on an adequate basis. Formations R.3-4 and R.5-6 thus represent, at least in part, the Barremian(?), Hauterivian, and Valanginian. Previous authors (Cuvillier and Debourle, 1954a, b) have assigned a Valanginian age to the R.5-6 zone on the basis of its similarity to the Valanginian described in Provence by Pfender (1938). Maync (1955) has already pointed out the discrepancies in age between the fauna described by Pfender from Provence and a similar fauna in Venezuela.

The problem of the age of formation R.5-6 and thus of *Cuneolina hensoni* is therefore not yet completely resolved. The formation is definitely lowermost Cretaceous, possibly Valanginian, but there is no certainty as to the validity of this last assertion.

#### DESCRIPTION OF THE NEW SPECIES

##### *Cuneolina hensoni* Dalbiez, new species

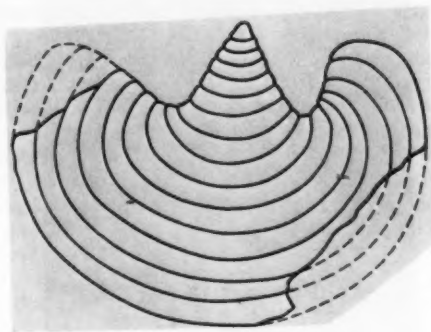
Plate 1, figures 1-6; plate 2, figures 1-5

Test calcareous, imperforate, microgranular. Shape triangular to strongly flabelliform, with the angles

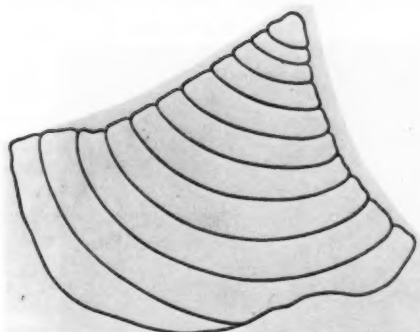
#### PLATE 1

1-6 *Cuneolina hensoni* Dalbiez, n. sp.

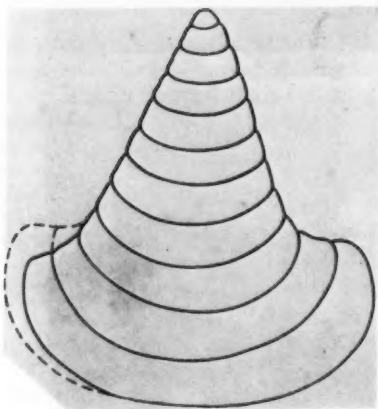
1-3, external views showing development of flabelliform shape; 4, drawing of an axial section; 5, subequatorial section,  $\times 60$ ; 6, subequatorial section,  $\times 63$ .



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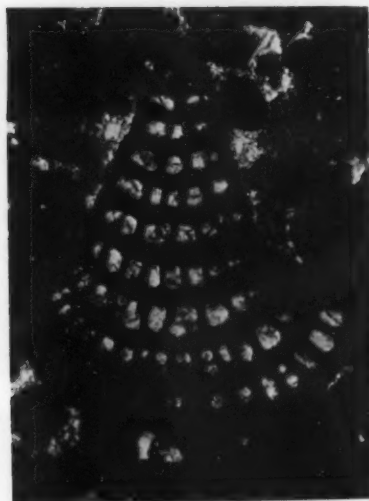
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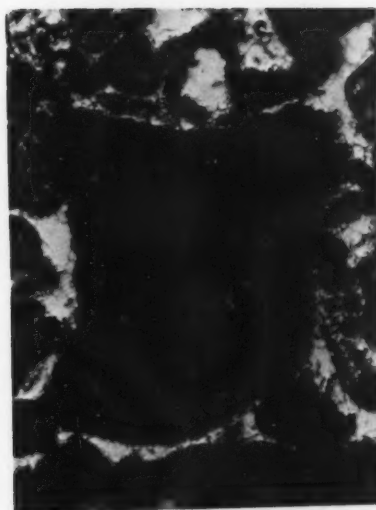
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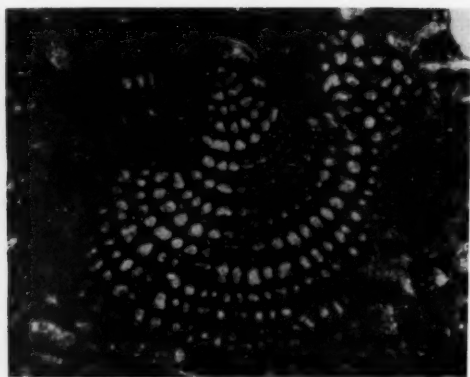
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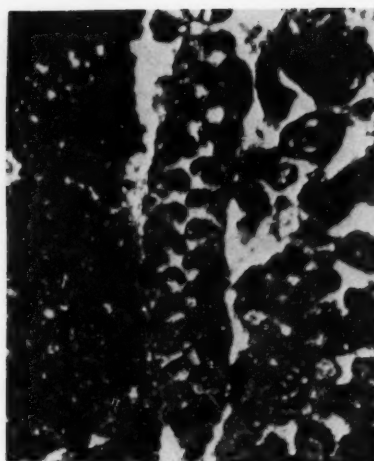
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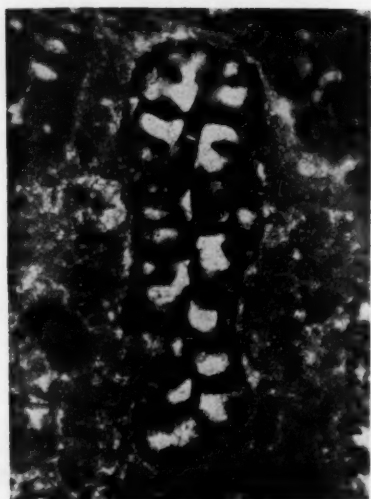
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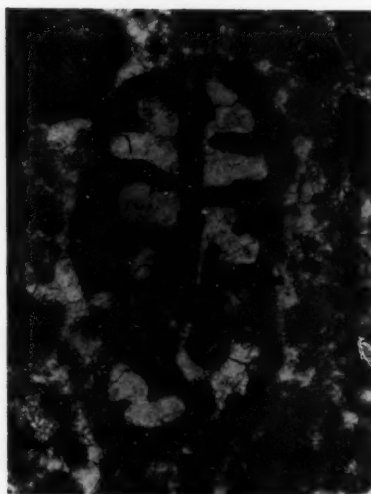
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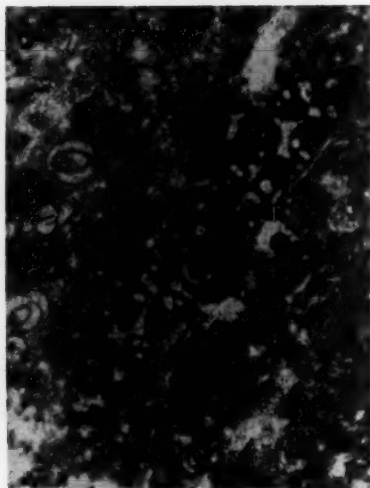
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5



6



# CUNEOLINA HENSONI

directed toward the initial end. Base convex. In the specimens observed, the apical angle varies from 40° to 70°. The thickness increases in the first three or four chambers, then remains constant up to the last one. There are ten to twelve chambers per millimeter, the maximum number of chambers observed in a flabelliform specimen being fifteen. The wall thickens considerably in the hook-shaped portion, as shown in transverse section. Transverse partitions well developed, producing eight chamberlets in a 30° sector in the adult, but parallel partitions seem to be completely lacking or have been absorbed by the thickness of the wall. A very feeble and sporadic development of one parallel partition per chamber is barely visible in some specimens.

The average height, or radial distance from apex to base, is 1.1 mm.; the width of the last chamber ranges from 0.8 mm. (in non-flabelliform specimens) to 1.5 mm. (in flabelliform specimens); the average thickness in the adult part of the test is 0.26 mm.

As suggested by Dr. F. R. S. Henson and A. H. Smout, who kindly reviewed this manuscript, *Cuneolina hensoni* is close to *Cuneolina walteri* Cushman and Applin, 1947, described from the lower Atkinson formation (middle Cenomanian) of Florida. Mrs. Applin has compared specimens of the two species, and states: "The major difference is that the internal structure of *Cuneolina hensoni* is much coarser than that of *Cuneolina walteri*."

The walls in *Cuneolina hensoni* are thicker, and in thin sections are represented by comparatively wide inter-chamber bands. At least one parallel partition is well developed in *Cuneolina walteri*. The transverse partitions of the chambers are almost as thick as the chamber walls and are few in number, as compared with the very thin and numerous radiating chamber partitions of *Cuneolina walteri*. This makes a marked difference in the shape of the chamberlets, which are narrowly rectangular in outline in *Cuneolina walteri* and roughly broadly rectangular (almost square) in *Cuneolina hensoni*. The sutures, in well preserved specimens of *Cuneolina walteri*, are slightly elevated above the outer surface, not depressed in *Cuneolina hensoni*. In size and shape the two species are closely similar, although I believe that the Florida species is slightly thicker."

*Cuneolina hensoni* is internally very different from the other Upper Cretaceous species. Its wall is considerably thicker, and it lacks the well developed parallel par-

titions. The transverse partitions are thicker, and the chamberlets which they form are much less numerous than in the Upper Cretaceous species (see pl. 2, fig. 6).

*Cuneolina hensoni* has been found in numerous wells in the Department of Landes, southwestern France, where it is frequent and restricted to the lowermost zone (R.5-6) of the Lower Cretaceous, immediately overlying shales with a Purbeckian brackish-water fauna. It is associated with *Dictyoconus* n. sp., *Choffatella* ex gr. *decipiens*, numerous Valvulinidae and Miliolidae, *Nautiloculina*, and *Clypeina inopinata*, in a para-reefal (Urgonian facies) limestone.

The syntypes are deposited in the Esso R.E.P. collection at Bègles, France.

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## PLATE 2

1-5 *Cuneolina hensoni* Dalbiez, n. sp.

1, subequatorial section,  $\times 39$ ; 2, axial section,  $\times 33$ ; 3, transverse oblique section,  $\times 63$ ; 4, transverse oblique section,  $\times 91$ ; 5, transverse oblique section,  $\times 39$ .

6 An Upper Cretaceous (Turonian) species from St.-Cyprien, Dordogne, showing the differences in the internal structure.



**ABSTRACT:** *The design, construction and use of a precision grinder for foraminifera and other small fossils are described. The electric micro-grinder, with its mechanical specimen feed and automatic cooling system, rests on the microscope stage, permitting one to watch the progress of the operation continually and to control it with great accuracy.*

## A precision sectioning instrument for microfossils

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### INTRODUCTION

Students of the foraminifera have long been aware of the need for sections in the study of larger representatives of the order, but in recent years it has become increasingly obvious that attention must also be devoted to the study of the internal structural features of smaller foraminifera if an adequate understanding of their phylogenetic relationships is to be gained. The difficulties attendant upon the preparation of critically oriented thin sections increase as the size of the tests decrease, however, and although numerous ingenious devices and techniques have been developed to facilitate the study of such minute internal features, much remains to be done in increasing the speed, precision and efficiency with which sections may be prepared. If an abundance of material is available, a worker may rely upon random sections obtained by grinding large numbers of specimens embedded within a natural or an artificial matrix, but if the supply is limited or if one wishes to study a single isolated specimen, the task becomes far more exacting.

Historically, the technical problem of preparing microfossils for a study of their internal structures has been attacked in at least three ways: (1) by grinding; (2) by microtomy; and (3) by solution and dissection. Grinding, the first method to receive widespread favor, was obviously fostered by geologists or persons directly influenced by them. Croft (1950) has traced the development of a series of fossil-grinding devices that bear the unmistakable imprint of mineralogists, crystallographers, petrographers, and gemmologists. The same influence can be detected in Birket-Smith's review (1950) of those grinding techniques which are devoted more specifically to the study of smaller fossils. Microtomy, by

contrast, was applied to the problem by biologists or persons working under their influence. Numerous biologists have prepared serial sections of infiltrated and decalcified foraminiferal tests, but Hofker (1926), Myers (1935), Vaughan (1945) and Birket-Smith (1950) have devoted particular attention to the study of internal morphological features by this method. Solution and dissection, the method which has most recently enjoyed popular favor and the one which probably requires the highest degree of manual dexterity, would seem to be a natural one for the micropaleontologist, although the use of needles to tear into delicate structures is an undeniable biological propensity, and the use of acids to dissolve calcite is an equally characteristic addiction of geologists.

While the following pages relate primarily to grinding, the instrument involved has the potential of offering successful competition in at least some of the peripheral regions of the spheres within which the other two methods exert their most effective influence. Without alteration, the micro-grinder is a powerful and efficient dissecting tool with which a student can easily create an artificial window at any desired point for examining a small fossil's internal structure. This can be accomplished with a degree of precision that probably exceeds that of the most skillful manual dissection. The grinder in its present form may also be used as a precision saw for cutting polished sections or series of thin wafers from such fossils as fusulinids, small orbitoids, bryozoa and ostracodes. By replacing the abrasive disc with a metal one formed from thin shim stock, smaller fossils can be sliced into wafers, an even closer approach to the serial section accomplishments of

the microtome. Through recourse to the extremely thin phosphor bronze discs used by diamond cutters (Grodzinski (1942) says that blades 60 microns thick are employed, but Willems (1948) reports that blades only 10 microns thick are now used), it should be possible to use this instrument for cutting the smallest foraminiferan without losing more than an insignificantly small part of the test to the saw's kerf. And if one is willing to perform the elaborate preliminary preparations required for making serial sections by the gelatin-paraffin method of Myers (1945) or by the celloidin-paraffin method of Birket-Smith (1950), the micro-grinder should be sufficiently adaptable to perform the role of either a well or a sliding microtome.

In an early phase of the author's current study of the inheritance of morphological variations within laboratory populations of a minute miliolid foraminiferan (adults average less than 150 microns in length at reproductive maturity, and immature forms range downward to 20 microns), the need for a rapid method of preparing precisely oriented sections of both mature and immature individuals became exceedingly acute. The instrument and techniques devised as a solution to the problem have made practical the task of sectioning large quantities of individually oriented specimens in a reasonable length of time. The relative simplicity of the design, construction, and use of the device, together with the general applicability of the principles involved, would seem to justify a detailed description for the micropaleontological public.

The speed and precision which characterize this micro-grinder result from the fact that the surface being ground is mounted directly in the field of vision of a stereoscopic microscope, and the specimen is fed into a small, electrically powered grinding wheel by

means of accurate mechanical controls. On the basis of personal experience in constructing the instrument, I would suggest that a competent machinist could easily construct one in less than twelve hours, the total cost of materials not exceeding ten dollars.

Special appreciation is due Mr. Howard Hamman, an artist on the staff of the Museum of Paleontology, for drafting the text-figures.

#### CONSTRUCTIONAL DETAILS

The sectioning device, which is illustrated in text-figure 1, consists of: (1) a brass channel and ways; (2) a vertically adjustable specimen carrier; (3) a brass slide or carriage which may be moved along the ways formed by the top edges of the channel walls; (4) a miniature electric motor equipped with a belt drive; (5) a fine-grained carborundum disc, which may be replaced by a glass lap when exceptionally small specimens are to be ground; (6) an automatic cooling system; and (7) a plastic splash guard.

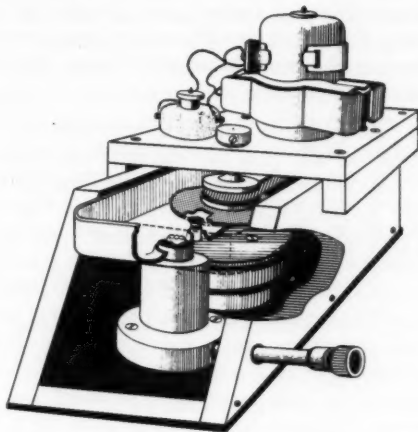
Dimensions accompanying the illustrations are appropriate for an instrument intended for use in sectioning most small foraminifera as well as some of the smaller large foraminifera (the motor is sufficiently powerful for efficiently cutting specimens up to two millimeters in diameter); but if very large specimens are to be prepared, its general capacity should be increased accordingly. It will become apparent to persons using an instrument of this type that some variation in relative proportions of the different elements is permissible. The height of the channel walls, for example, needs to be only sufficient to permit the free passage of the lap over a specimen attached to the lowered specimen carrier.

#### TEXT-FIGURES 1-3

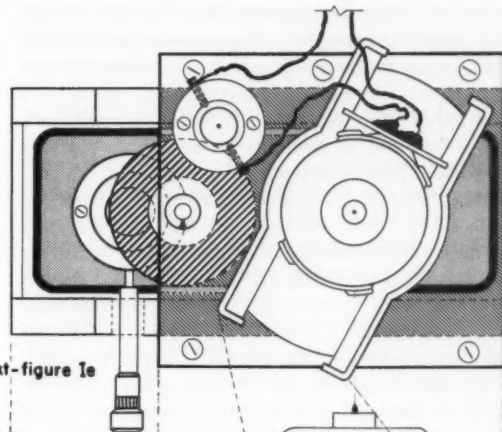
- 1a Precision micro-grinder with all parts in operating position; cutaway section shows relation of water reservoir and wick to abrasive disc.
- 1b Cross-section along vertical plane parallel to front of instrument, cutting through center of specimen carrier and lap assembly; carriage has been advanced to the cutting position in this figure, as well as in text-figures 1c and 1e; water reservoir included, although it lies behind plane of section; figure drawn to scale (distance along base of micro-grinder = 3 inches).
- 1c Section parallel to side of instrument, cutting through center of specimen carrier, water reservoir and carriage; motor has been rotated from its true position (shown in text-figure 1e) for clarity; the switch is shown, although it actually lies behind plane of section; figure drawn to scale (distance along base of micro-grinder =  $1\frac{1}{2}$  inches).
- 1d Vertical section of switch, showing constructional details.
- 1e Top view of precision micro-grinder, drawn to scale.
  - 2 Electrically operated tool for orienting and infiltrating microfossils; cap not shown.
  - 3 Cylindrical fixture for cementing glass lap to its arbor; arbor, lap and cement are in place.



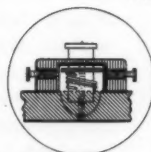
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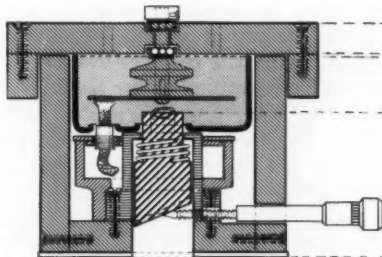
Text-figure 1a



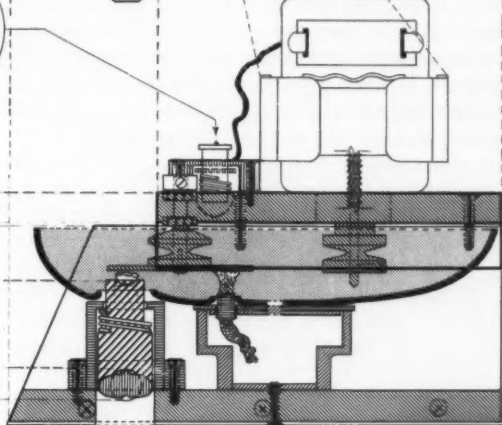
Text-figure 1e



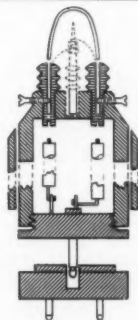
Text-figure 1d.



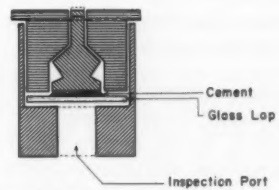
Text-figure 1b



Text-figure 1c



Text-figure 2



Text-figure 3

A moderately excessive amount of clearance between the specimen and lap can be eliminated by fusing additional cement onto the carrier and mounting the specimen on top of the elevated pedestal thus formed for it. Additional possibilities for varying the proportions of the component elements are mentioned at appropriate places in the discussion that follows.

Both the channel and the lap carriage should be constructed of one-quarter-inch brass stock, because the resulting weight lends stability to the instrument and eliminates the need for clamping devices when it is in use on the stage of the microscope. The channel in which the specimen carrier is mounted, and along whose top the grinding assembly slides, is composed of three pieces of brass screwed together, the essential constructional requirement being only that the top edges of the two side pieces are rigid, smooth, parallel, and horizontal. The channel should be at least one-fourth longer than the grinding assembly, to provide adequate support for the latter whether it is in a functional position over the specimen or in a disengaged position at the opposite end of the ways. It should be wide enough not only to permit free passage of the lap but also to permit the operator free access to the specimen carrier as he orients objects upon it, a process that requires the most precise free-hand manipulation of heated tools, often under relatively high magnifications. The front of the channel should be sloping, to permit free access to the specimen carrier. A piece of one-sixteenth-inch rubber sheeting should be glued to the base of the channel to provide increased stability and to protect the glass stage of the microscope from scratches.

The specimen carrier, turned from solid brass stock, consists of a spring-loaded piston activated by a finely threaded control screw whose point travels in a groove milled across the bevelled base of the piston. These elements are joined and held in place on the floor of the channel by means of a mounting collar. A hole drilled in the channel accommodates the extended lower end of the piston as the specimen podium is retracted into the cylinder. Additional details of the carrier assembly are shown in the cross-sectional illustration in text-figure 1b.

The essential requirements for the specimen carrier are: (1) that it be perpendicular to the lap; (2) that the vertical travel of the specimen podium be at least one or two millimeters more than the length of the greatest axis of the specimen; (3) that the thread of the control screw be sufficiently fine to give the operator full control over the grinding speed; (4) that the point of the screw and the groove in which it

travels be smooth and so shaped as to impart an even movement to the piston at all times; and (5) that the spring within the cylinder be of sufficient strength to force the piston steadily against the control screw whenever the screw's pressure upon the piston is relaxed.

The first of these requirements may be met by making certain that all machine cuts are square, that the cylinder is carefully bored, that the polished piston fits snugly, and that the ways of the channel are properly ground and polished. The second requirement may be fulfilled by making certain that the exposable length of the specimen podium be a few millimeters longer than the greatest axis along which specimens are to be sectioned and that the total length of usable threads exposed on the control screw be at least as great. The third requirement was met through the use of a 2-56 thread, a size which can easily be adapted for instruments of widely diverse capacities. The amount of vertical rise resulting from one revolution of the control knob (about 90 microns in the case of the illustrated instrument) is a function of the number of threads per inch and of the angle of inclination of the base of the piston. If the angle is reduced, the vertical rise per revolution of the screw is reduced, providing increased precision. In satisfying the fourth requirement, particular attention should be devoted to grinding and polishing the point of the screw. This will present erratic movement as the piston is thrust upward toward the lap; it is, of course, also necessary that the point of the screw fit snugly into the groove, so as to prevent any rotational movement by the piston, and that the point be sufficiently long to prevent the threads of the screw from touching either the groove or the inclined surface of the piston. The fifth requirement is easily met by experimentation, but the writer has found that number 7 music wire wound into three complete turns with an overall uncompressed height of 9 millimeters is suitable for an instrument of the indicated specifications. The spring was initially wound onto a mandrel whose diameter was slightly less than that of the specimen podium; after being cut to size, it then fit snugly around the podium and performed its function well and unobtrusively. Since operators undoubtedly have different preferences concerning the final pressure which they wish to apply to the control knob in order to obtain the desired degree of precision in feeding the specimen into the lap, the ultimate composition of the spring should be varied to suit individual tastes.

The lap carriage consists of a two-by-two-inch square of one-quarter-inch brass, against the longer

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edges of which are screwed two pieces of rectangular stock. In order to obtain a sliding fit between the carriage and the ways on which it rides, the two should be hand-lapped after having been ground initially to a tight fit. More elaborate measures for obtaining and preserving the desired fit (such as the addition of gibs and surfaces of harder metals) may be employed if desired, but are hardly necessary, since a slight lateral movement of the carriage has no influence on the critical alignment between specimen and lap if the construction of the other elements of the instrument has been executed in accordance with the indicated specifications.

The two most important requirements for the motor that drives the lap are that it be sufficiently small to permit easy manipulation of the carriage and sufficiently powerful to permit effective grinding within the intended capacity of the instrument. A wide variety of miniature direct-current motors is available for use in instruments of this type, some of the readiest and least expensive sources being hobby shops and war-surplus outlets. Although less powerful motors are adequate for grinding smaller foraminifera, the author suggests the use of a 6-volt one, since these generally have the power necessary for most small foraminifera and for some of the smaller orbitoids and fusulinids.

Needless to say, careful attention should be given to the instrument's transmission system. The diameter of the motor pulley should be minimal, and that of the lap pulley maximal, to obtain a ratio favorable for the development of the greatest power and lowest speed without recourse to external gears. Although a single fine-grained lap will suffice for a wide variety of operations, it is occasionally desirable to be able to change to a coarser one for more rapid grinding if a large specimen must be sectioned, or to a glass disc if an exceptionally small one must be sectioned. The face of the pulley to which the abrasive disc is fastened may be as large as the disc itself, but the alternate pulley to which the glass lap is fastened must be several millimeters smaller in diameter than the lap, so that the specimen can be viewed directly through the lap with the microscope. A pulley which is to bear an abrasive disc should be drilled to receive a 2-56 screw so that discs of different grain-size may be employed; the one which is to bear a glass lap should have concentric grooves turned in its face to facilitate cementing the two elements together. The motor pulley may be fastened to its shaft with either a screw or a pin, but since the lap pulley and shaft are turned as one piece, the entire assembly, complete with lap, should be removable by loosening a retaining collar which also serves as a dust cap for

the upper set of bearings. Little difficulty will be encountered in exchanging lap arbors if they have been carefully fitted to the bearings. Small rubber rings, employed as gaskets and commonly known as "O" rings, make suitable transmission belts, but if such rings are unavailable, a serviceable belt can be prepared by cutting a ring from a piece of laboratory tubing of suitable diameter mounted on a mandrel in the lathe. A razor blade is an efficient tool for the purpose, and with a little care the cuts can be made in such a way as to produce a belt whose cross-sectional shape closely approximates that of the grooves into which it is to fit. The distance between the two shafts should be determined to suit the belt as closely as possible. If, after this distance is set, the proper driving fit is not obtainable with the first belt, additional belts of different widths can easily be prepared; the intelligent utilization of the variation in flexibility which results from altering this width is often the secret to the construction of an efficient transmission system. A simple sleeve bearing for the lap arbor will give satisfactory results for a program of intermittent sectioning, but if an intensive schedule is anticipated, the installation of two races of miniature ball bearings in the carriage will prove a worthwhile and not excessively expensive investment.

The final element to be added to the carriage is a small switch, which is placed so as to bring the action of the motor and lap under the direct and convenient control of the same hand that moves the carriage, thereby freeing the other hand for the additional tasks related to the sectioning operation. The illustrated carriage was designed for operation with the right hand, but since this relationship is determined largely by the position of the switch, other workers should experience little difficulty in converting it for left-hand use. It is possible to purchase switches of a suitable size for this instrument, but an efficient one (text-figure 1d) can easily be made if a commercial source is not known. The housing for the switch was turned from clear acrylic, a material which is a non-conductor and easy to work. The two lateral screws serve as electrical contacts at their inner ends, while their fillister heads make convenient mounting lugs. Grooves to receive the wire and direct it to the screws were cut on one side of each screw-hole by means of a jeweler's circular saw. The screw-holes should be countersunk to such a depth that the wire can be pinned securely and safely within the resulting recess.

A wide variety of inexpensive abrasive discs is available for an instrument of the indicated dimensions. The most common sources include sup-

pliers of dental, horological, jewelry and hobby materials. The judicious choice and careful use of abrasive discs will yield acceptable results in sectioning a wide variety of paleontological specimens. For routine sectioning of small foraminifera (ranging downward to 200 microns), a fine dental separating disc has proved adequate. Discs are readily changed on the illustrated arbor; the glass lap, mounted on its own arbor, may be kept in readiness for unusually small specimens. The writer relies almost exclusively upon abrasive discs, since they are generally faster and less complicated to use than glass laps. The principal advantage of the latter is that it is possible to look through them with a microscope at all times, directly onto the surface being ground. One can use clear or frosted laps, the former requiring the continual addition of abrasive in a fluid vehicle, the latter requiring only a cooling fluid for their successful operation. If clear laps are used, they should be changed with each change in abrasive grain-size, but the simple expedient of using abrasives of different grain-sizes to frost concentric circles on the face of one lap eliminates this need. The coarsest frosting should be outermost, the finest innermost, so that centrifugal force will prevent loose particles from damaging the finely frosted area. Round cover-glasses of the type employed by microscopists make suitable laps, although even the thickest ones (no. 2) must be used with extreme caution to prevent breakage. Rather than laminating two or more of these together to form a more sturdy lap, one would be well advised to cut a disc from a thin microscope-slide (using a piece of copper tubing rotated in a cutting fluid of light oil and carborundum), since this is far more durable and if used with reasonable care should satisfy one's needs through many hours of rigorous sectioning.

A satisfactory cement for attaching the glass disc to its arbor is the thermoplastic resin known as "Lake-side Number 70" (Meyer, 1946; Von Huene, 1949; Emiliani, 1951), commonly employed by petrographers and paleontologists. The task of affixing the lap to its arbor can be accomplished by heating the two simultaneously and pressing them together with an appropriate amount of cement sandwiched between, but they are seldom found to be either parallel or concentric with one another after the cement cools, unless some mechanical means of insuring proper alignment is utilized. A simple and effective fixture for achieving this alignment is illustrated in text-figure 3. The device consists of a brass cup into which the lap fits snugly, and a brass sleeve which can be made to slide into the cup with slight manual pressure. The sleeve is drilled to re-

ceive and hold the arbor in a concentric position. A viewing port in the base of the cup permits the operator to inspect the progress of the operation without removing the arbor. In use, the arbor, with its warm cement-coated face, is thrust into the sleeve, and both are lowered into the cup until contact is established between cement and lap. The entire unit is then heated until the lip of the sleeve can be pressed flush with the edge of the cup and the arbor pressed firmly against the lap. The brass cup and sleeve distribute the heat evenly and permit slow cooling so that the glass is not subjected to excessive strain during this critical period. The cooling process may safely be accelerated through artificial means if the few minutes so saved are critical, but the entire procedure requires less than five minutes even when cooling is allowed to progress at a normal pace.

The automatic cooling system by which water is applied to the specimen and lap consists of: (1) a reservoir tank; (2) a wick which presses against the lap and continuously feeds water onto its under surface; and (3) a removable splash tray which collects the water spun off from the wheel and returns it to the reservoir tank for re-use.

The reservoir consists of a brass cup screwed to the base of the channel and covered by a brass cap which bears the wick housing and a port through which water is added and eventually returned by gravitational flow. A short length of cotton twine serves well as a wick. The cap fits snugly into the cup but can easily be removed along with the splash tray when access to the wick or cup is required, because the cap is cemented to the under surface of the tray. Although the original design and the prototype of this instrument have a metal cap for the reservoir, the writer suggests that the cap be molded as an integral part of the plastic splash tray, eliminating the metal cap altogether. The reservoir itself is fastened to the channel by means of a screw, so that it can easily be removed for cleaning when a troublesome quantity of abrasive and test debris accumulates in it. The splash tray rests securely on the reservoir and the housing of the specimen carrier, but is easily removed to permit free access to the specimen carrier during the operation of orienting a specimen or removing a finished section. A flexible but leak-proof seal between the tray and the specimen carrier can be effected by forming a diaphragm-like gasket from liquid latex or molten polyvinyl chloride, spread and allowed to harden within the opening through which the specimen carrier must pass. A paper tray (waxed to make it waterproof), or one fashioned from fairly stiff aluminum foil, can serve



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as a splash guard, but a more durable and efficient one is well worth the time invested in its construction. The illustrated plastic tray was first constructed as a dental-wax model from which a two-piece plaster mold was prepared. The final reproduction was a casting of acrylic resin strengthened with spun glass. A person with some experience in handling these materials should be able to complete the process from model to finished casting in six hours.

### THE SECTIONING PROCEDURE

#### Infiltration

Specimens to be sectioned should be cleaned as well as possible before being subjected to further treatment, as it is much easier to follow the course of grinding if one's vision is not obscured by adherent debris. This precaution will also prevent fragments of debris from becoming dislodged during the grinding operation and damaging the section. Before the specimen is actually sectioned it should be infiltrated as much as the nature of the test and its natural openings will permit. The need for infiltration varies with the structural strength of the test and can best be determined by observation and experience, but for unfilled specimens the writer generally recommends infiltration, if consistently superior results are desired. The slight additional time and effort required to achieve adequate infiltration almost invariably prove to be a rewarding expenditure. The aim of infiltration should be to fill *all* accessible cavities within the test, so as to afford maximum support for both internal and external structures during the preparation of the section. If it is feasible to heat the specimen, it is generally a simple matter to fill the most resistant test, especially if an artificial entrance is first provided for the infiltrating material by making a preliminary tangential pass through the test wall with the abrasive disc. With the micro-grinder, the difficulties and dangers attendant upon making such an opening are minimal. It is a simple matter to achieve complete infiltration by fusing thin threads of cement into the opening by the use of the electric orienting tool described in a subsequent paragraph.

A suitable infiltrating medium for most purposes is "Lakeside Cement Number 70," the same material as that used in embedding the specimen and affixing it to the specimen carrier. It may occasionally be desirable, however, to employ a medium whose color is sufficiently different from that of the surrounding test to afford a degree of contrast conducive to even more precise control over the grinding operation. In this case, one can resort to a wide variety of

cements and/or pigments now available through the distributors of synthetic resins and thermoplastic substances. Some of the media suggested by Glaessner (1945), Stach (1949), Kremp and Johst (1951), Zeidler (1951) and Hagn (1953) could also be used with the micro-grinder.

Satisfactory infiltration can sometimes be accomplished by heating specimens in a suitable resin on a glass slide held over an open flame or heating element; but if many sections are to be prepared, a worker would do well to equip himself with an electric tool of the type illustrated in text-figure 2, or a compact and efficient miniature hot plate which can be used on the stage of the microscope to permit him to observe the progress of the operation with certainty and confidence. The writer prefers to infiltrate specimens individually after they have been artificially opened with the micro-grinder, in which case the entire operation of embedding, infiltrating, orienting and sectioning can be accomplished without removing the test from the specimen carrier. Other workers may prefer to employ miniature hot plates, and will find that King (1938) and Goerlich (1953) have designed hot plates which should be adaptable for infiltrating specimens that have relatively large apertures. Imaginative students should experience little difficulty in developing equally efficient units from the wide variety of ceramic and electrical materials that today can be easily obtained and fabricated by the amateur.

#### Orienting and embedding

The problem of orienting the specimen critically may most conveniently be solved through the use of electrically heated manipulatory tools, although cruder methods will produce results for a patient worker. Beckmann (1951) described a tool specifically designed for such a task, and Levinson (1953) has detailed the electrical materials he employed in adapting the idea for use in America. Designs proposed by Fabergé and LaCour (1936) and by Buck (1938) for tools to be used in orienting biological materials in paraffin prior to microtoming could equally well be modified for use in orienting microfossils. An instrument designed by Labzoffsky (1948) for dispensing molten paraffin has features which might well be incorporated in a tool for orienting, infiltrating and embedding foraminifera.

The implement illustrated in text-figure 2, built within the case of a discarded fountain pen, is compact and efficient in operation. Its nichrome wire heating element is easily replaced or reshaped, and the cooling fins on the wire-holding brass sockets

prevent the case from becoming overheated. Power for the unit is supplied by an inexpensive 6-volt filament transformer and regulated by a 25-ohm potentiometer. The tool itself is connected to the power source by a miniature plug which becomes an integral part of the plastic housing. When the instrument is not being used, the fountain-pen cap fits snugly over the resistance loop to protect it from damage.

It is wise to use a cool needle in conjunction with the electric tool in orienting and transferring specimens, since a heated test or section readily adheres to a cool surface but not to one which is itself sufficiently hot to melt the mountant. The writer uses a fine needle (shaft diameter of 220 microns, tip diameter of 34 microns) of the type called "*minuten Nadeln*" by entomologists, as this is small enough for manipulating most foraminifera effectively and safely. Cannon (1940) has described a method for making still finer needles by dipping tungsten filament-wire into fused sodium nitrite to sharpen the tip. Specimens adhering to the needle during transfer between carrier and slide may easily be removed by touching the heated loop to the needle, a technique which is often equally valuable in positioning the specimen upon the carrier. The dotted lines inserted between the two brass sockets at the tip of the electric orientation tool were added to indicate the simplicity of adapting such a device to accommodate a heated needle. A few turns of resistance wire serve as a heating coil for a small needle, and a set screw penetrating the needle's socket holds the needle firmly in place. Cooling fins should also be turned on the needle socket to prevent overheating the plastic housing.

Experience will soon reveal the need of having enough cement around the specimen to give it structural support during sectioning, but in the interest of efficient and rapid grinding an effort should also be made to reduce the overall area of the ground surface (including specimen and surrounding cement) to its safest minimum. Although excess cement may easily be removed with the electric orienting tool, much time can be saved by preparing cement sticks of an appropriate diameter which can be fused onto the specimen carrier and used as short pedestals in which the specimen may be embedded.

#### Cutting and mounting the section

Before power is applied to the lap, it should be moved into position over the specimen and a final check should be made to determine that the desired

alignment between lap and specimen has been obtained. The edge of the activated lap may then be used to remove any excess cement that may have been left overlying the specimen during the embedding process. It is often easier and safer to expose the specimen's upper surface by means of the lap or grinding disc rather than by use of the resistance loop, since the former can be controlled with greater precision. Once the specimen and lap have been properly aligned, sectioning may proceed without interruption.

In use, the lap carriage should be pressed firmly against the ways as successive passes are made over the specimen carrier. Between each pass the specimen can be viewed with the microscope and thrust upward by means of the vertical control knob near the base of the channel. The amount of pressure required to obtain efficient cutting, as the specimen is forced into the lap, varies with the instrument, and can best be determined by actual experimentation. In a similar way, the rate at which grinding proceeds is best left to the judgment of the operator, as the optimum rate is influenced by a number of variables, including the nature of the specimen, its embedding and infiltration medium, and the grain-size of the cutting agent.

Most of the writer's preparations are polished sections (i.e., ground and polished on one surface only), rather than thin sections, because the writer, like Kremp and Johst (1951), has found the examination of polished sections by incident light just as revealing, for many purposes, as the study of thin sections by transmitted illumination. Moreover, it is often a definite advantage to be able to retain half of the test with its inner structures conveniently exposed to view and its external features intact. In preparing a polished section with the micro-grinder, the rapid—almost cinemascopic—unfolding of a sequence of sections before the eyes of the operator gives a spectacular impression of the test's internal organization, and affords a unique opportunity to gain an understanding of these relationships. A camera or camera lucida mounted on the microscope at this time would enable a student to obtain a record of the sequence which could serve as a tangible substitute for the stages that are inevitably lost in penetrating to the most critical level of the test.

Should one desire thin sections, these can be prepared with no greater difficulty than is encountered in their preparation without the micro-grinder. A specimen that has been ground on one side is simply inverted on its carrier by means of the electric loop and cool needle, and then ground to the desired

## SECTIONING INSTRUMENT

thickness. In some cases it is safer to affix a cover-glass to the specimen carrier and to cement the polished surface of the specimen directly to it before grinding the second side, as a firm support is thereby provided for its protection during subsequent handling. A glass lap is a decided advantage at this time, because with it the progress of the grinding can be followed more closely. After the specimen's second side has been ground and cleaned, the cover glass and section are removed as a unit and affixed to a slide by means of a drop of piccolyte or other mounting medium. The cement which adheres to the exposed surface of the cover-glass can be removed with one of the solvents suggested by Emiliani (1951). The procedure for transferring and mounting polished sections is simpler than that for thin sections, as the former may simply be removed from the specimen carrier with a needle, transferred to a dish of cleaning solution (in which the remnants of abrasive and cement are brushed away), and finally glued to a standard micropaleontological slide by means of gum tragacanth. A specimen may be cleaned before it is removed from the carrier, but the most effective way of accomplishing this with all but the smallest tests is to let the needle cool with the specimen adhering to it, after which the specimen can be rotated into any desired position and brushed with solvent while held securely to the point of the needle.

With the micro-grinder, the electric orienting tool, and the techniques described for their use, a dexterous micropaleontologist should be able to prepare a polished section of an average small foraminiferan in one to five minutes (including picking, infiltrating, orienting, grinding, cleaning and mounting) with a degree of precision far exceeding that obtained by present methods. The writer hopes that this description will encourage micropaleontologists to use an instrument of this or similar design to overcome some of the technical obstacles that currently make an extensive or intensive study of internal features of small foraminifera such an excessively time-consuming project. Students of larger foraminifera, as well as paleontologists in general, could easily adapt the principles employed in this design to the development of precision grinders for sectioning a wide variety of fossil types.

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## A sorting device for smaller foraminifera

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The palaeontologist is often confronted with a collection of several hundred specimens belonging to perhaps twenty or thirty species, after preliminary picking has been completed with a perforated picking tray with an underlying slide. He is then faced with the task of dividing the microfauna into taxonomic units. This process normally involves continual transfer of specimens from the picking slide to a museum slide by means of a brush or needle, with the attendant risk of loss. When a large number of taxonomic units are being dealt with, their locations on the museum slide may be forgotten, and much time lost. Moreover, in order to compare specimens (variants, for example), it is necessary to transfer them to a museum slide. Also, with this method it is difficult to mount the units in the order of their correct families, because there is no way of knowing, until picking is concluded, how many units per family there will be. Remounting is therefore necessary. It is not practicable to pick, for example, all specimens of species A and then all of species B and so on, as this method is very slow, laborious, and inefficient. The sorting device described in the present note eliminates these problems without, as far as known, introducing any fresh ones.

This device, which in the present case is designed to fit the stage of the new Zeiss Opton binocular microscope, is illustrated in text-figures 1 and 2. Text-figure 1 is an exploded view, and text-figure 2 is a section along the line 2—2 in text-figure 1.

As seen in text-figure 1, the device consists of three main elements: the main block (1), the top plate (2), and the bottom plate (3). The top plate shown is one of three, any one of which may be used according to the magnification (and hence the size of field) desired. Each top plate has a black-bottomed tray (4), in which the microfossils to be sorted are placed, and two holes (9 and 10), into which the fastening screws (7 and 8) fit. The holes (5) pe-

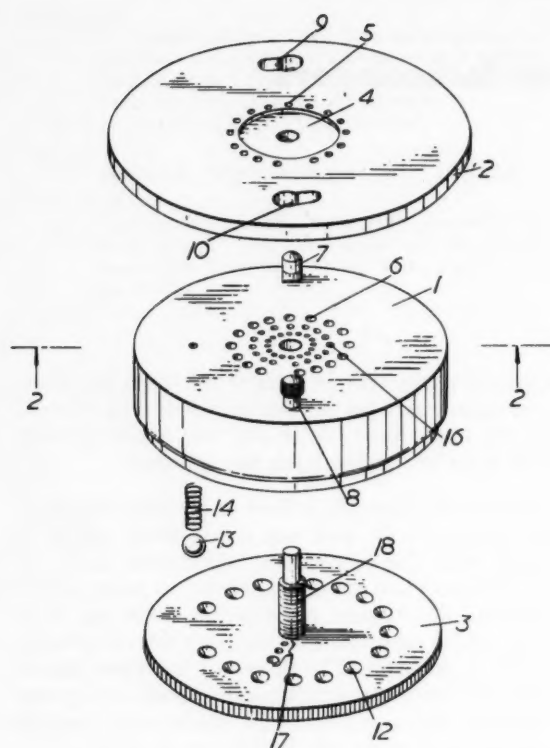
ripheral to the tray in each of the three top plates correspond to respective sets of cylinders (6, 16, etc.) in the main block. Note also the blank position, which carries neither holes nor cylinders.

The bottom plate (3) is fixed to the main block (1) by a screw (18), and can rotate freely about its centre axis. The contact faces of the main block and the bottom plate are machined flat to make perfect contact. The bottom plate carries three exit holes (17), which correspond to the three sets of cylinders in the main block. The three exit holes are aligned with the three sets of cylinders by means of a spring-and-ball device (13 and 14), which snaps into the conical depressions (12) in the bottom plate.

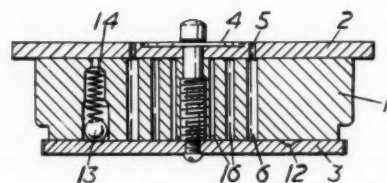
The microfauna to be sorted is placed in the tray (4) in the top plate, and each peripheral hole (5) is indexed by placing next to it one or two specimens from each group. Subsequent specimens are dropped into the holes (5) and fall into the cylinders (6, etc.), which act as receptacles. The specimens cannot fall out of the cylinders because the exit holes (17) in the bottom plate are aligned with the blank position in the top plate and main block referred to above.

When sorting is completed, the index specimens are added to their respective cylinders, the device is removed from the stage, and the contents of each cylinder are transferred to a standard Franke slide or other suitable receptacle by rotating the bottom plate (3) by its milled edge until one of the exit holes (17) is aligned with each of the cylinders (6, etc.) in turn. A few taps will serve to clear any specimens that stick in a cylinder.

This device has been used by the writer for more than a year, with complete success. During this period, not a single specimen has been lost or damaged, and the sorting of extensive microfaunas has been greatly facilitated.



TEXT-FIGURE 1



TEXT-FIGURE 2

## Models of foraminifera



A second casting of our models of foraminifera has been made, and sets of these models are now ready for distribution. The genera represented in these sets of fifty models are all well-established forms that have been generally accepted by specialists in foraminifera. Type species have been used where possible, but as forms with spines and keels are too fragile for teaching purposes, it has not always been possible to

do so. Forms that are otherwise highly ornamented have been avoided also as the cost of casting and finishing them would be prohibitive.

The models are not to scale as the size range would have been too great for practical purposes. In general most of the forms are about three inches along their greatest dimension. Globular forms have been made somewhat smaller. A brochure with labeled illustrations is supplied with each set.

The price is \$75.00 per set, post-paid anywhere in continental United States. The postage on foreign shipments must be paid by the purchaser. Inquiries and orders should be directed to:

Department of Micropaleontology  
The American Museum of Natural History  
Central Park West at 79th Street  
New York 24, New York.



## Alcide d'Orbigny (1802-1857)

It seems appropriate to recall Alcide d'Orbigny's memory on the centenary of his death (June 30, 1857). He was a prodigious worker, and specialists in many fields of paleontology cannot help being impressed by the amount of work he did, as well as by the accuracy of the observations made by this master of paleontology. His qualities as a scientist are becoming even more widely appreciated as more and more micropaleontologists work with the genera and species that he established.

His life and works have been fully recorded by Fischer, Heron-Allen, and other authors, and the reader is requested to refer to them. I would like at this time to attempt to portray the personality of this pioneer of paleontology. When he was eleven years old, he began to study "Histoire Naturelle," with the help of his father. Later on, and little by little, he worked on a tremendous amount of material gathered on his own collecting trips or sent to him by his friends. In this almost unexplored field of research, his very advanced ideas and strong logical mind made him the founder of a universally accepted classification of the "Foraminifera," a group of highly evolved organisms. He revised all the forms previously worked on by Soldani and other authors, and classified them according to Linné's taxonomic system.

Alcide d'Orbigny became the first Professor of Paleontology at the Paris Museum, but he died

shortly after he had assumed this highly distinguished position, which he considered to be the summit of his scientific career. He was fifty-five years old when he died. He was buried at Pierrefitte, near St. Denis, on July 2, 1857.

d'Orbigny named over 1000 species, most of which are still valid. He died before being able to complete his plan of publishing the countless observations he had made during his lifetime. His manuscripts include numerous etchings, drawings and three-tone color plates, which are compiled in his "Planches Inédites." These priceless illustrations, which were, in part, redrawn and published by Fornasini, have been greatly admired by those who have been lucky enough to be permitted to examine them. When we realize how primitive the Nineteenth Century optical equipment was, we can easily understand how difficult it must have been for d'Orbigny to differentiate, classify, and accurately draw such small-sized animals. He did not want to be the only one to be able to observe his types, and consequently made his own collection of plaster models accessible to everyone.

All of this precious material, including the original collection of foraminifera, from the museums of La Rochelle and Paris, is now deposited in the paleontological laboratory and gallery of the Paris Museum of Natural History. To enhance the value of his collections, it is proposed to establish a d'Orbigny museum. Such a museum would enable specialists from all over the world to become acquainted with d'Orbigny's entire collection, original writings, and unpublished manuscripts. In addition, the file, containing over 1200 species, could be completed and checked.

All are amazed by the breadth of his scientific knowledge, which extended to a large range of animals, and by the fact that he was an authority not only on micro-organisms but also on larger animals; space is lacking here to recall his important works on Bryozoa, corals, echinoderms and cephalopods. In the field of micropaleontology, he was the first to realize the importance of "correlation," and thus to emphasize the importance of taxonomic studies of foraminifera as a basis for comparison between two geologic formations representing facies variations. Such microfaunal analyses are fundamental to our modern coring log system and to the basin correlations that are derived from them, as well as to paleogeography and paleoecology on a larger scale.

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# news reports

## AUSTRALIA



IRENE CRESPIN

The micro-examination of extensive rock collections made by geologists of the Bureau of Mineral Resources, Geology and Geophysics, Canberra, in North-West Australia, Northern Territory, western Queensland, and New Guinea keeps the micropalaeontologists of the Department fully employed. These collections are supplemented by surface and bore material from private companies engaged in the search for oil. Microfossils are being found commonly in rocks of all ages throughout the Commonwealth, and much new material is awaiting description. Amongst these are widely distributed radiolaria-bearing rocks of Lower Cretaceous (upper Albian) age.

The writer has just completed a Bulletin on the Permian foraminifera of Australia, in which new genera and many new species are described. It was during this investigation that the two genera *Streblospira* and *Flectospira*, recently described by Crespin and Belford, were discovered. D. J. Belford is studying the Upper Cretaceous foraminiferal fauna of Western Australia. P. J. Jones is engaged in an investigation of Upper Palaeozoic Ostracoda, which are especially abundant in surface sediments. He is making a special study of the genus *Cryptophyllus*, which is

common in the Carboniferous and Upper Devonian of Western Australia. The Bureau staff of micropalaeontologists will shortly be increased with the arrival from England of P. R. Evans, who will devote his time to the study of microplankton.

Investigations of extensive collections of macrofossil material of Lower Palaeozoic age from different parts of Australia by Dr. A. A. Öpik and Miss J. Gilbert-Tomlinson has revealed excellent conodont faunas. Dr. B. F. Glenister and his American wife are preparing publications on Australian conodonts.

Dr. Isabel Cookson and her staff, of the Botany Department, University of Melbourne, are continuing their studies on microplankton, pollen, and spores, whilst B. E. Balme is engaged in this work at the University of Western Australia. Dr. M. F. Glaessner and his staff at the University of Adelaide are working primarily on Australian Tertiary foraminifera. Dr. N. H. Ludbrook is carrying out investigations for the Department of Mines of South Australia. A. N. Carter is the micropalaeontologist at the Department of Mines in Melbourne. A. C. Collins, of Geelong, Victoria, is continuing his study of Pleistocene and Recent foraminifera.

IRENE CRESPIN

Bureau of Mineral Resources,  
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## AUSTRIA

The editors of MICROPALAEONTOLOGY have received the following communication, dated September 9, 1957, from Mr. C. E. Totten, Manager of the News and Information Division, Public Relations, of the Shell Oil Company, New York:

"In the April number of MICROPALEONTOLOGY, Rudolf Grill, in his news report from Austria, referred to Dr. Klaus Küpper's work. It is with deep regret that we have to inform you of Dr. Küpper's death in May of 1957 in Nigeria, where he was working with the Shell-BP Petroleum Development Company of Nigeria Limited. Although only in his 26th year, Dr. Küpper had shown great promise, and his death came as a great shock to his colleagues."

## BENELUX



J. H. VAN VOORTHUYSEN

## BELGIUM

University of Louvain, Coal Museum

Dom Remacle Rome, O.S.B., Director of the Paleontological Museum of the University of Louvain, has nearly finished his study of the ostracode genus *Cryptophyllus* in the Belgian Paleozoic, which is expected to be published shortly. He is now engaged in an investigation of the genus *Bairdia*. This is painstaking work, because he is forced to extract the little carapaces from the very hard rock with a needle. I wonder if there are some ostracode specialists who could give Dom Rome some advice on how to disintegrate this rock, which would save him a good deal of time.



**University of Louvain, Geological Institute**

Dr. F. Gullentops informs your correspondent that, among other activities, he is continuing his studies of Tertiary foraminifera.

**University of Liège,  
Laboratory of Micropaleontology**

Professor Ubaghs is still engaged in the study of Neogene microfaunas from the Cuanza sedimentary basin of Angola. He reports the discovery of the *Globigerinatella insueta* and *Globigerina dissimilis* zones. The first appearance of *Orbulina universa* in Angola is recorded from the highest parts of the *Globigerinatella insueta* zone. Mr. Meyer has been working on the problems involved in fixing the Cretaceous-Tertiary boundary.

**Royal Belgian Institute of Natural Sciences,  
Botanical Section, Brussels**

In the Contributions de l'Institut Royal des Sciences Naturelles de Belgique (vol. 32, no. 30, June, 1956), Dr. R. Vanhoorne published a paper entitled "Étude palynologique de la Fange aux Mochettes à Samrée (Belgique)."

**Royal Belgian Institute of Natural Sciences,  
Paleontological Section, Brussels**

Professor Lecompte's brother has reported that Professor Lecompte was unable to report on the activities of his laboratory because of illness. We sincerely hope that Professor Lecompte will soon be well again.

**NETHERLANDS**

**University of Leiden**

During the summer of 1956, Professor van der Vlerk was the guest of Dr. Storrs Cole at Ithaca, New York, Dr. Alfred Loeblich in Washington, and Dr. R. Wright Barker in Houston, Texas. In the course of these travels, he studied *Lepidocyclina* material. He is now engaged in a revision of the *Lepidocyclinas* of Borneo and Sumatra.

Students of Professor F. Florschütz have analysed peat samples from Austria and from the Rhône Valley in France. As Director of the Paleobotanical Laboratory of the Government Agricultural Experiment Station at Velp, Province of

Gelderland, Professor Florschütz is engaged in studying peat samples from France and Spain.

**University of Utrecht**

Dr. C. W. Drooger, Conservator of the Geological Institute, has published a paper jointly with W. H. Akers, of New Orleans (1957, Amer. Assoc. Petr. Geol., Bull., vol. 41, no. 4, pp. 656-678), dealing with miogypsinids, planktonic foraminifera, and Gulf Coast Oligocene-Miocene correlations. They recommend further study of Oligocene-Miocene planktonic foraminifera, as they are convinced that the stratigraphic relationships between miogypsinid species and planktonic foraminifera in the Gulf Coast offer the key to world-wide correlation and the proper application of some of the European terminology.

In my news report published in January, 1956, I mentioned that Dr. A. J. Key had nearly finished his study on the Eocene and Oligocene ostracodes of Belgium. Since that time, this very extensive study, with twenty-three plates, has been published (1957, K. Belg. Inst. Natuurwetensch., Verhandl., no. 136).

A study by Dr. D. A. J. Batjes, entitled "Foraminifera of the Oligocene of Belgium," will be published soon in the same series. Dr. Batjes has paid close attention to modern trends in stratigraphy, especially facies changes in the Oligocene of the Belgian sedimentary basin. In particular, he questions the exactness of the general use of the Tongrian-Rupelian-Chattian sequence as a tripartite division of the Oligocene into chrono-stratigraphic units.

Dr. F. P. Jonker, Conservator of the Botanical Museum and Herbarium, informs me that pollen-analytical research in the Dutch Holocene and late-glacial peat has been continued by two students. C. R. Janssen is engaged in a study of the history of the late-glacial and Holocene vegetation of the Cretaceous district in the south of the Dutch Province of Limburg. As a preliminary result, it can be reported that there is indeed

a considerable difference between this area and the northern part of the Netherlands. His study will last at least two years, and will be presented as a doctor's thesis. A. A. Manten has been studying a lignite profile from the Anna Quarry at Haanrade, Limburg, with a thickness of 17 meters. This lignite has turned out to be very rich in species. Mr. Manten dates it as Lower Miocene, and it is comparable with the lower part of the lignite in the German Lower Rhine district.

**University of Groningen**

Professor H. T. Waterbolk, Director of the Biological-Archaeological Institute, reports that he and his Conservator, Dr. W. van Zeist, have continued their investigations of the subsoil of prehistoric barrows. Dr. van Zeist has also continued his work on the raised bogs near Emmen. Some interesting peat discoveries have been investigated, for example a Neolithic trackway at Nieuw Dordrecht and a Bronze Age temple at Barger Oosterveld. From two standard diagrams, characteristic pollen horizons were absolutely dated by means of the radiocarbon method. Other students have been working on further botanical and archaeological problems.

**University of Amsterdam**

Professor Dr. J. Heimans, Director of the Hugo de Vries Laboratory Hortus Botanicus, reports that his students are engaged in the following studies: Miss M. R. Walvius is investigating peat samples from a mound (terp) at Schagen, Province of North Holland; Mrs. W. Groenman-van Waateringe is studying a Holocene peat layer overlying the marine clay north of Schagen, samples from an old barrow surface (Hunebed Cr. 1) at Noord-Laren, Province of Groningen, and samples from a barrow of the early Bronze Age at Weelde, Province of Antwerp, Belgium.

Professor MacGillavry announces that his two papers mentioned in the previous news report from Benelux (1956, Micropaleontology, vol. 2, no. 4) have been published. The

paper on *Lepidorboides* appeared in 1955 (Netherlands, Geol. Stichting, Meded., new ser., no. 9, pp. 11-43), and the one on evolution in *Cyclolcypeus* in 1956 (K. Nederl. Geol. Mijnb. Genoot., Verh., vol. 16, pp. 296-308). An additional paper, entitled: "Danger of world-wide correlations based on evolving features" and dealing, among other things, with his findings on *Lepidorboides*, was read by MacGillavry at the Cretaceous Symposium of the International Geological Congress in Mexico.

Identifications of Globotruncanidae by R. J. Elsinga, and of *Trocholina* and "*Protopeneroplis*" from Corsica, and the stratigraphic implications, were included in two studies on the geology of Corsica. One, by W. Bosma, was entitled "Contribution à la géologie de la Balagne," and was published at Amsterdam in 1956 as his thesis. The other, by T. de Booy, was entitled "Nouvelles observations sur la série sédimentaire de la zone Caporalino-San Angelo au sud-est de Francardo, Corse" (1957, K. Nederl. Akad., Wetensch., Proc., ser. B, vol. 60, no. 3).

**Geological Bureau of the Netherlands Coal Mining District, Heerlen**

For Dr. S. Dijkstra, the past year has been a productive one. He has published the following papers: "Carbonische megasporen en hun practische betekenis" (1956, Jaarb. Mijnb. Ver., 1956-57, 15 pp.); "Some Brazilian megaspores, Lower Permian in age, and their comparison with Lower Gondwana spores from India" (1956, Netherlands, Geol. Stichting, Meded., new ser., no. 9, pp. 5-10, pl. 4); "Lower Carboniferous megaspores" (1957, Netherlands, Geol. Stichting, Meded., new ser., no. 10, pp. 25-38, 11 pls.); and (together with M. C. Bonet) "Megasporas carboniferas de La Camocha (Gyon)" (1956, Estud. Geol., vol. 12, no. 31-32, pp. 245-266, pl. 10). He has in press a paper in collaboration with P. Piérat, "Some Lower Carboniferous megaspores from Moscow," which is expected to appear in 1958 (Netherlands, Geol. Stichting, Meded., new ser., no. 11, with many plates). He

also has in preparation a paper entitled "Some Paleocene megaspores and other small fossils."

**Geological Survey of the Netherlands**

The study of the continental Pliocene stratigraphy by W. H. Zagwijn, who is in charge of the Palaeobotanical Laboratory, was completed during the past year and will soon be published as a doctor's thesis. In addition, Mr. Zagwijn has published two important papers on the Pleistocene of the Netherlands: "Zum heutigen Stand der pollenanalytischen Untersuchungen des Pleistozäns in den Niederlanden" (1956, Geol. en Mijnb., new ser., vol. 18, pp. 426-427), and "Vegetation, climate and time correlations in the early Pleistocene of Europe" (1957, *ibid.*, vol. 19, no. 7, pp. 233-245).

The revision of the type locality of the Eemian (Riss-Würm interglacial), the little River Eem, which empties into the former Zuyderzee, has been successfully carried out. New information has been gained concerning interstadia during the Würm glacial epoch. The results will be published in due course. Much time has also been spent on pollen-analytical investigations of the Holocene. A more and more detailed picture of the vegetation during Holocene time has been obtained.

A. van der Werff is doing very well as a diatom specialist. He is now assisted by H. Huls, who was formerly an amateur but who was so attracted by the wonderful structure of the diatoms that he has now decided to make his living studying them. Van der Werff is working principally on ecological problems of the Holocene and Pleistocene. An exhaustive study of the diatoms of the type locality of the Eemian (see above) disclosed a typical diatom flora characterized by species from a warmer climate, such as are now living in the Mediterranean. In connection with a study to determine the possibility of manganese concentration in the subsoil by diatoms, several Recent samples from the tidal-flat area have been studied. Van der Werff has now

begun the study of diatoms collected during the field-work of the ecological and sedimentological study of the Eems estuary.

Your correspondent has recently published a paper entitled "The Plio-Pleistocene boundary in the North Sea Basin" (1957, Geol. en Mijnb., new ser., vol. 19, no. 7, pp. 263-266). Along with routine work, he has nearly finished a study of the Recent foraminifera of the Eems estuary and the foraminifera of the Eemian stage. A paper entitled "A geological reconnaissance of the geology of the province Zeeland till 40 m depth," including Eocene to Recent deposits, is in press.

**The laboratory of Dr. Jan Hofker, The Hague**

The results of Dr. Hofker's research on the boundary between the Campanian and Maestrichtian in the Netherlands and northeastern Belgium have been published in a paper entitled "Les foraminifères de la zone de contact Maastrichtien/Campanien dans l'est de la Belgique et le sud des Pays-Bas" (Ann. Soc. Géol. Belgique). Another publication is "Planktonic foraminifera of the Chalk Tuff of Maastricht and environs" (Natuurhist. Maandbl., vol. 45, pp. 51-57). Evidence of a faunal break at the lower boundary of the Chalk Tuff is shown. A third paper was "*Coleites reticulosus* and its development" (Natuurhist. Maandbl., vol. 45, pp. 75-78). The species has been found ranging from the Upper Cretaceous, where it still had all the characteristics of a *Pseudoparrella*, into the Paleocene.

Dr. Hofker has also published on "The species of the genera *Gavelinella* and *Gavelinopsis* in the Cretaceous above the Hervian in Germany, Holland and Belgium, and the increase of the diameters of their pores as indication for stratigraphic levels" (Natuurhist. Maandbl., vol. 45, pp. 99-110, with a range chart). Another paper in the same volume (pp. 131-132) was "The development of *Eponides beisseli* Schijfsma," in which Dr. Hofker shows that a sharp-edged form of the lower Maestrichtian changes into *Eponides*

*beisseli* in the upper Maestrichtian and finally into *Eponides franki* Brotzen, which is found in the uppermost part of the Maestrichtian. In his paper "Foraminifera dentata; Foraminifera of Santa Cruz and Thatch-Island, Virginia-Archipelago, West-Indies" (*Spolia Zoologica Musei Hauniensis*, vol. 15), Dr. Hofker describes the cycle of generation, the inner structure, and the taxonomy of a large number of species. In a study entitled "The development of *Sigmomorphina soluta* Brotzen and of *Sigmomorphina brotzeni* nov. sp.," he indicates that the second species, which was presumably derived from the first by mutation, shows parallel development with it.

Other recent papers are: "The development of *Pararotalia tuberculifera* (Reuss)" (*Natuurhist. Maandbl.*, vol. 46, pp. 32-39); "Some more planktonic foraminifera from the Lower Md in the Quarry Curfs, Houthem" (*ibid.*, vol. 46, pp. 57-58); and "*Globorotalia praetuberculifera* nov. spec." (*ibid.*, pp. 59-60). At present four species of the genus *Globorotalia* are known, all indicating a Tertiary age.

J. H. VAN VOORTHUYSEN  
Geological Survey of the Netherlands  
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## CARIBBEAN AREA



PAUL BRONNIMANN

The news report on the Caribbean area, including Central America, supersedes the one on the West Indies, which was restricted geographically to the Caribbean islands.

It covers a widespread area, and although your correspondent has first-hand knowledge of most of the laboratories in Central America and the Caribbean, its content depends largely on information obtained from the individual paleontologists. He takes this opportunity to express his thanks to all those who, during the past years, have contributed news on personnel, routine work and research.

## CUBA

J. P. Beckmann, formerly with The Trinidad Oil Company, is now a paleontologist with the Cuban Stanolind Oil Company in Havana. A. Wirz and Beckmann are working on the zonation of the Tertiary of Oriente Province, Cuba. They are especially interested in the correlation of reefal and planktonic faunas.

The laboratory of the Cuba California Oil Company in Havana is staffed by A. Martínez and P. Norton. Prior to this assignment, Martínez, who is the senior stratigrapher and paleontologist, was with the Richmond Exploration Company in Maracaibo, Venezuela. He will be working on regional stratigraphic problems. Norton, a paleontologist, is studying surface and well samples from Cuba, the Bahamas, and the Gulf Coast. M. Furrer was transferred from the Cuba California Oil Company first to Guatemala, on a temporary basis, and then to the California Ecuador Petroleum Company in Guayaquil, where he is in charge of the geological laboratory.

P. Bronnimann has left the Cuban Gulf Oil Company and has joined Esso Standard Oil, S. A., as head of the new geological laboratory in Havana. This laboratory is engaged in micropaleontologic and stratigraphic work throughout the Caribbean area and Central America. Your correspondent has continued his research on pseudorbitoids and planktonic microfossils. Together with N. K. Brown, Jr., he has published a short note on Upper Cretaceous rotaliids from Cuba and Jamaica (1957, *Micropaleontology*, vol. 3, no. 1, pp. 29-38).

The geological laboratory of the Cuban Gulf Oil Company in Havana was moved to the Foreign Production Division of the Gulf Oil Corporation in New York. N. K. Brown, Jr., is in charge of this laboratory, in which micropaleontological work for the Western Hemisphere will be centralized. Type material referred to in papers by Bronnimann, and by Bronnimann and Brown, as being deposited in the collections of the Cuban Gulf Oil Company has also been transferred to New York.

In a paper on Eocene larger foraminifera from Cuba by K. N. Sachs, Jr. (1957, *Cushman Found. Foram. Res., Contr.*, vol. 8, pp. 106-120), *Operculinoides bermúdezi* (Palmer) and certain discocyclinids are restudied. All the representatives of de Cizancourt's "nummulites cordelées" from Barbados and Venezuela are placed in synonymy with *Operculinoides bermúdezi*. *Bontourina* Caudri (genotype *Bontourina inflata* Caudri, from the Eocene of Trinidad, B.W.I.) is regarded as a synonym of *Discocyclina* Gümbel.

G. A. Seigle, geologist with the Comisión de Fomento Nacional, a Cuban government agency, is studying the Upper Cretaceous stratigraphy of the Jatibonico area in southern Camagüey Province. He has a note on some Upper Cretaceous planktonic foraminifera in preparation.

## JAMAICA

Drilling and surface exploration have been discontinued by the Pan Jamaican [Oil] Company. W. R. Weaver, who previously did the micropaleontological work on the Jamaican samples in Stanolind's Havana laboratory, is now engaged in stratigraphic studies in Cuba.

W. Storrs Cole, of Cornell University, has published two notes dealing with Jamaican Tertiary larger foraminifera. In the first note (1956, *Bull. Amer. Pal.*, vol. 36, no. 158), *Pellatispirella matleyi* (Vaughan) is redescribed, and criteria are proposed for the recognition of *Miscellanea* and *Pellatispirella*. The second



note (1956, Bull. Amer. Pal., vol. 36, no. 159) is a study of Eocene to Miocene larger foraminifera from fifty Jamaican localities.

#### TRINIDAD

No changes in personnel are reported from the laboratory of the Dominion Oil Company, Ltd., in Port-of-Spain. E. T. N. Spiker has been transferred from Venezuela to the laboratory of Shell Trinidad in Point Fortin. J. P. Beckmann has left The Trinidad Oil Company and has joined the Cuban Stanolind Oil Company in Havana. Max Carter is a new paleontologist with The Trinidad Oil Company in Pointe-à-Pierre.

In a well illustrated paper which represents the first part of a study of the Trinidad Lower Cretaceous foraminifera, Bartenstein, Bettenstaedt and Bolli (1957, *Eclogae Geol. Helv.*, vol. 50, no. 1, pp. 5-68, pls. 1-8, 3 text-figs.) have described the benthonic foraminifera of the probably lower Barremian Toco formation and the middle to upper Barremian Cucho formation. The Trinidad assemblages are closely related to those of northwestern Germany and the northern Alpine region, although the Barremian ammonites found in the tethyal environment of Trinidad and in the boreal environment of Europe belong to different genera and species. This seems to demonstrate the adaptability of Lower Cretaceous benthonic foraminifera to widely different environments and their usefulness in regional and worldwide correlation. Your correspondent, together with Ruth Todd, has completed a paper on the Recent foraminifera and *Thecamoebina* of the eastern Gulf of Paria (1957, *Cushman Found. Foram. Res.*, Spec. Publ. no. 31).

In a study of the variation of *Lepidocyclina* from the Oligocene Morne Diablo limestone of southern Trinidad, Cole (1957, Bull. Amer. Pal., vol. 38, no. 166) has discussed the fundamental characters of American Oligocene and Miocene species of *Lepidocyclina* (*Lepidocyclina*). The specific features are the general shape of the test (stellate or not stellate),

the shape of the equatorial chambers in the later neanic stages (diamond-shaped to hexagonal), and the arrangement and shape of the lateral chambers and the development of the pillars as seen in vertical section. The key to these forms given by Cole (op. cit., p. 33) will be very useful to all who work with random sections of *Lepidocyclinas*.

#### GUATEMALA

The Compañía Petrolera California, Ltd., has established a geological laboratory in Guatemala City, with H. V. Kaska in charge. Kaska previously worked for The California Company in Trinidad and in San Francisco. A committee on stratigraphic nomenclature has been set up by the companies exploring in Guatemala in order to arrive at a uniform stratigraphic system. G. Dengo, of the Union Oil Company of California, is chairman, and H. V. Kaska is vice-chairman of this committee.

#### COSTA RICA

Paleontologists with the Compañía Petrolera de Costa Rica, a subsidiary of the Union Oil Company of California, are Mrs. Ora Willet and H. Browne. The laboratory is located in San José, Costa Rica.

#### PANAMA

In a paper on the late Oligocene larger foraminifera of the Bohio and Caimito formations on Barro Colorado Island, Panama Canal Zone, Cole (1957, Bull. Amer. Pal., vol. 37, no. 163) has reviewed the classification of the American miogypsinids and heterosteginids. Although Cole regards Drooger's (1952, *Study of American Miogypsinidae*, Utrecht, Univ., doct. diss.) statistical approach to the classification of the miogypsinids as sound, he believes that it is (1) overinfluenced by minor variations, and (2) difficult to use by the industrial paleontologist. In Cole's classification, the five species of American miogypsinids belong to the subgenera *Miogypsina* (*Miogypsina*) and *Miogypsina* (*Miogypsinoides*). *Miogypsinella* Hanzawa, *Miogypsinopsis* Hanzawa, and *Miogypsinita*

Drooger are suppressed. Keys are presented to the genera and species of American miogypsinids (Cole, op. cit., p. 317) and to the four species of *Heterostegina* occurring in the American Eocene and Oligocene (ibid., pp. 326, 327). The paper is copiously illustrated by photographs of oriented sections of *Miogypsinas* and *Heterosteginas*.

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#### ISRAEL



Z. REISS

#### The Hebrew University

Professor M. Avnimelech, of the Department of Geology, is continuing his studies on the monothalamous foraminifera. Several students are working on foraminifera under the guidance of Professor Avnimelech, toward their M.Sc. degrees. Among the faunas studied are those of the Red Sea (Recent), as well as larger foraminifera from the Oligocene of this country. Cretaceous and Tertiary foraminifera are being investigated by other students for stratigraphic purposes. Your correspondent has continued lecturing on the foraminifera at the Hebrew University within the framework of a special course. Two recent publications by Professor Avnimelech have contained lists of foraminifera: "Oculinid corals in the Lower Eocene of Nazaret Mountains" (Hebrew Univ., Geol. Mus., Rec., no. 2), and "Découverte de *Stratodus* (Teleostei: Dercetidae) dans le Sénonien supérieur d'Israel" (Soc. Géol. France, C. R. Somm., no. 2).



#### Geological Survey of Israel

In the summer of 1957, Professor Avnimelech resigned his position as head of the Paleontology Division of the Survey in order to devote himself fully to teaching and research at the Hebrew University. Your correspondent has temporarily assumed the duties of head of the Division, in addition to his duties as micropaleontologist in charge of the Survey's Laboratory of Micropaleontology. The staff of the latter laboratory has been increased during the past year, and now comprises, in addition to your correspondent, five assistants. Routine work for the departments of the Geological Survey and for various exploration companies searching for oil, water and economic mineral deposits has continued and has greatly increased the amount of information on the microfaunas of various ages of this country.

A fairly large research program initiated about two years ago has also continued to be carried out. The details of this program are given below:

#### Mesozoic

Research on the Jurassic has made some progress, but a large amount of material is still awaiting study. A short note on the occurrence of *Protopenoplis striata* Weynschenk has been prepared by your correspondent and is now in press (Israel, Geol. Survey, Bull., no. 17). Several thousand samples from the Lower Cretaceous, from outcrops and wells, have been studied in an attempt to determine the stratigraphy of these strata in more detail. Both microfacies and microfaunas are being used for this purpose. The investigation is being carried out by your correspondent and Mrs. K. Klug, of the Micropaleontology Laboratory. About 3000 photomicrographs of typical microfacies have already been prepared and incorporated in a card catalogue.

A complete Lower Cretaceous sequence, ranging in age from Berriasian to Vraconian, has been found to occur in the subsurface of western

Israel. Surface exposures of marine Lower Cretaceous strata are restricted to Aptian-Vraconian deposits.

The first of a series of publications on the microfacies and microfaunas of the Lower Cretaceous of Israel has been completed in cooperation with the Survey's Oil Division and will be sent to the printer in the near future. It includes about 250 photomicrographs and a distribution chart of the main faunal elements, as well as lithologic and electric logs.

More intensive work on the Cenomanian-Turonian of Israel has been begun, and a large amount of material awaits detailed study. Special attention is being paid to the "larger" and the imperforate foraminifera. This project is being carried out by your correspondent in cooperation with the Mapping Division of the Survey.

Several research projects started earlier have been shelved for the time being, including studies of Upper Cretaceous *Neoflabellina*, microfaunas from the Campanian phosphate deposits of Israel, and others. Publications (some of which are still in press) dealing with foraminifera from the Cretaceous of Israel include a short note on *Nezzazata* (Reiss, 1957, Micropaleontology, vol. 3, no. 4), the description of a new gumbelinid genus, *Sigalia* (Reiss (in press), Israel, Geol. Survey, Bull., no. 17), and a note on the foraminiferal fauna of the late Cenomanian - early Turonian of Israel (Reiss, 1957, Israel, Geol. Survey, Bull., no. 11).

#### Cainozoic

In connection with the mapping of the western part of southern Israel, more attention has been paid to the "larger" foraminifera (Nummulitidae, Miscellaneidae, Discocyclinidae, etc.). Paleocene strata containing *Nummulites*, *Discocyclina*, *Asterocyclina*, *Miscellanea*, *Daviesina*, and others, in addition to characteristic "smaller" foraminifera, have been discovered for the first time in Israel. Certain deposits, regarded by earlier authors

as belonging to the Middle Eocene, Upper Eocene and even the Oligocene, have been shown by their foraminiferal faunas to belong to the Lower Eocene (Ypresian). They contain, among other forms, rich populations of *Cuvillierina eocenica* Debourle. A short paper on the occurrence of *Cuvillierina* has been published by your correspondent (1957, Israel, Geol. Survey, Bull., no. 10). Papers published on Tertiary foraminifera include, in addition, a note on *Truncorotalia aragonensis caucasica* (Glaessner) and the description of a new genus, *Loxostomoides* (1957, *ibid.*, no. 9), as well as a paper dealing with *Eorupertia* and *Victoriella* (1957, *ibid.*, no. 11).

#### Quaternary

A research project in cooperation with the Water and Mineralogy Divisions of the Survey and with the T.H.L., Israel Water Planning Authority, was started early in 1957. It involves the Pleistocene deposits of this country. Your correspondent and two assistants, Misses Mor and Plotkewicz, are carrying out a statistical study of the microfaunas of these deposits. The resulting graphs are to be compared with those obtained from heavy-mineral analyses, as well as with lithologic logs. Several wells have been analyzed up to the present, with excellent results.

#### General stratigraphy

Your correspondent has published a distribution chart of selected genera, subgenera and species-groups from the late Jurassic to the Pliocene of Israel (1957, Israel, Geol. Survey, Bull., no. 11). It is shown that fairly exact stratigraphic determinations can be carried out without reference to specific determinations, especially if various species belonging to the same genus and exhibiting certain common characters are grouped together.

#### Systematics

Your correspondent, assisted by Mrs. P. Merling, has undertaken a revision of the calcareous and

aragonitic perforate foraminifera. The first results of this investigation have been summarized in two papers now in press, "The Bilamellidea, nov. superfam., and remarks on the Cretaceous globorotaliids" (1957, Cushman Found. Foram. Res., Contr., vol. 8, pt. 4), and "Classification of lamellar foraminifera" (1958, Micropaleontology, vol. 4). It has been shown that the superfamily Discorbidea Smout comprises distinct groups of foraminifera, for which your correspondent has proposed two new superfamilies, based primarily on the wall structure. Good correlation has been found between wall structure and Hofker's classification according to apertural characters. All calcareous and aragonitic, regularly perforate foraminifera have been found to have lamellar structure, and have been subdivided into six superfamilies: Buliminidea Glaessner, Lagenidea Glaessner, Rotaliidea Glaessner emend. Smout, part of the suborder(?) Uniloculinidea Sigal, and the new superfamilies Monolamellidea and Bilamellidea. One of the above-mentioned papers is concerned especially with the structure and classification of the Cretaceous globorotaliids. Three new genera (*Globotruncanella*, *Globotruncanita* and *Helvetoglobotruncana*) have been erected for species hitherto referred to *Globotruncana* or *Globigerina*. This investigation is being continued.

A card catalogue of all foraminiferal genera, with pen-and-ink drawings and photomicrographs, is being prepared by Mrs. Merling for the Laboratory's use, and is nearing completion.

Z. REISS

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## NEW ZEALAND



N. DE B. HORNIBROOK

The past nine months have brought a considerable increase in micropaleontological activity in New Zealand. Dr. W. A. van den Bold (Shell) and Dr. F. Kicinski (B.P.) arrived in January and set up laboratories in Wellington and Gisborne to do micropaleontological work for the exploratory geological parties working in the North Island. Paul Vella is doing part-time foraminiferal work for Todd Bros. Oil Exploration Division, a local company with leases in the North and South Islands. Vella's paper "Studies in New Zealand foraminifera" (New Zealand, Geol. Survey, Pal. Bull., no. 28) has been published and is available on an exchange basis from the Geological Survey, P.O. Box 8002, Wellington. Unfortunately, Dr. van den Bold had only a short stay before returning to The Hague. He has been replaced by Dr. M. Geiger, who arrived in July. During the ANZAAS conference at Dunedin in January we had the pleasure of visits from Dr. Nellie Ludbrook of South Australia and Allan Jenkins of Aberystwyth University, Wales.

Dr. R. A. Couper is carrying on his work on New Zealand Mesozoic and Tertiary spores and pollen at the Geological Survey. His Ph.D. thesis, "British Mesozoic microspores and pollen grains," is being published in "Palaeontographica," and will appear early in 1958. Dr. W. F. Harris, at present with the Soil Bureau, has joined the Geological Survey and will work with

Dr. Couper on New Zealand Upper Tertiary and Quaternary spores and pollen.

George Scott has completed his M.Sc. thesis on the distribution of foraminifera in the Oligocene Otaio River section, and has joined the Geological Survey as a micropaleontologist. Dr. J. T. Kingma is continuing his work on New Zealand late Tertiary foraminifera at the Geological Survey.

Your correspondent has summarised the foraminiferal evidence for overseas correlation of the New Zealand Upper Cretaceous and Tertiary in a paper submitted to MICROPALaeONTOLOGY, and, in collaboration with Dr. H. J. Harrington, has published a paper entitled "The status of the Wangaloan stage" (1957, New Zealand Jour. Sci. Technol., sec. B, vol. 38, no. 6, pp. 655-670). This paper deals with Cretaceous-Tertiary boundary problems in New Zealand.

By the early part of 1958, the Geological Survey will be established in a new modern building in the city of Lower Hutt, about seven miles north of Wellington. This will mean a considerable expansion in space and facilities for micropaleontology.

N. DE B. HORNIBROOK  
Geological Survey of New Zealand  
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## POLAND



FRANCISZEK BIEDA

The present report concerns work done in Poland between October, 1956, and September, 1957. To

complete the picture we shall also mention some brief paleontological papers that appeared during the past two years in a monthly journal published only in Polish, in Warsaw, called "Przegląd Geologiczny" (Geological Review). The latter periodical publishes work of a stratigraphic character, which contain lists of micro-organisms, without descriptions of species. Papers published in other Polish periodicals are supplied with summaries in congress languages.

First we will consider papers on foraminifera from the Carpathian flysch and the Miocene, then papers on spores and pollen, and finally papers on other micro-organisms.

The results of stratigraphic studies based on the micropaleontology of material from the flysch of Węglówka, north of Krosno, are presented by Miss F. Huss (1957, *Acta Geologica Polonica*, Warsaw, vol. 7, no. 1). The author gives lists of foraminifera from the geologic unit called the Węglówka unit, which might also be called the sub-Silesian unit. The flysch series begins with black slates of Barremian age, and ends with the Krosno beds, of probable Oligocene age. There are eleven plates illustrating foraminiferal associations, and six tables listing the foraminifera from various bore-holes. In the Cretaceous, the author determined about 150 species of foraminifera; in the Paleogene, about sixty species. Some species are common to both the Cretaceous and the Paleogene.

Another paper, by Mrs. Janina Liszka (1956, *Przegląd Geologiczny*, Warsaw, no. 10), deals with the stratigraphy of the sub-Silesian series of the flysch in the Polish Carpathians, on the basis of the microfauna. The material was collected from nearly the entire Carpathian arch in Poland, beginning with Bielsko in the west and extending to Sanok in the east. The author has determined the foraminiferal associations from the Cenomanian to the Upper Eocene. In some associations there is a preponderance of arenaceous foraminifera, in others of calcareous ones. Lists of the foraminiferal faunas are given, as well as

tables showing their distribution within the stratigraphic scheme of the Polish Carpathian flysch.

Another Cretaceous-Tertiary sequence based on microfauna was reported on by H. Kozikowski and A. Jednorowska (1956, *Acta Geol. Polonica*, vol. 6, no. 4). In this paper the junior author gives lists of foraminifera from the Magura unit in the Słonica Valley, south of Żywiec. The fauna consists exclusively of arenaceous foraminifera of the Upper Cretaceous and Eocene. Under the Magura overthrust, flysch rocks of another geologic unit also appear, and contain an arenaceous fauna, among which are the characteristic forms *Cyclammina amplexans* Grzybowski and *Cystammina subgaleata* Vašíček. These species indicate a Middle Eocene age.

S. Geroch (1957, *Pol. Tow. Geol., Rocznik*, Krakow, vol. 25 (1955), no. 3) has written a paper on the little-known species *Uvigerinammina jankói* Majzon. This species, belonging to the family Verneuilinidae, is found in the Polish Carpathians in sediments of the Upper Cretaceous and Eocene.

Foraminifera of the Paleogene of the Carpathians of Poland and other countries are treated in the following papers: F. Bieda (1957, *Pol. Tow. Geol., Rocznik*, vol. 25 (1955), no. 3) reports on the occurrence of the larger foraminiferal genera *Grzybowskia*, *Spiroclypeus* and *Operculinoides* in the Upper Eocene, in both flysch beds and limestone beds, in the Carpathians of Poland, Czechoslovakia and Bukovina (U.S.S.R.). The genus *Grzybowskia*, described by Bieda in 1950, is revised, and a new, emended diagnosis is given. It is important to note that the genus *Operculinoides*, which occurs in the Western Hemisphere, has been found in the Carpathian flysch. The author describes six species and illustrates them with photographs.

In another paper, published in Czechoslovakia (1957, *Geologický Sborník*, Bratislava, vol. 8, no. 1), the same author presents the results of the determination of larger foram-

inifera of Upper Eocene age from sixteen different localities in Slovakia. He describes fourteen species of *Nummulites*, *Operculina* and *Orbitolites*. On the basis of these faunas, the Upper Eocene in the Slovakian Carpathians can be divided into three separate levels.

The smaller foraminifera of the Upper Eocene of Grabno, near Brzesko, are the subject of a paper by S. Liszka (1957, *Pol. Tow. Geol., Rocznik*, vol. 25 (1955), no. 3). The author has identified a fauna consisting of ninety-nine species of foraminifera, of which only seventeen species are arenaceous, the others being calcareous. He describes and gives figures of forty-five species and varieties, among which three species and one variety are new. He mentions the occurrence of as yet undetermined Radiolaria, Diatomaceae, and Bryozoa, and the gastropod *Spiralis*. A fauna of this kind had not previously been found in the Polish Carpathian flysch; this is the first rich fauna to be described from the Menilite slates level, in which fish remains are found but foraminifera are very rare. This fauna shows a resemblance to the *Globigerinoides conglobatus* association found in the Caucasus and in Moravia.

A problem which presents great difficulties in the stratigraphy of the Carpathian flysch has been the determination of the age of the rocks called the "gray Cretaceous." These levels and the underlying sub-Grybów marls, together with the basal Grybów shales, appear in tectonic windows near the northern border of the Magura unit. They were formerly included in the Upper Cretaceous, but the discovery by F. Bieda of Upper Eocene larger foraminifera in the sub-Grybów marls (results of work not yet published), and a paper on smaller foraminifera by H. Kozikowski and A. Jednorowska (1957, *Przegląd Geologiczny*, no. 3), have made it possible to determine that the entire complex, i.e., the Grybów shales, the sub-Grybów marls, and the uppermost level, called the "gray Cretaceous," belongs to the Upper Eocene and Oligocene.



The Miocene, which is represented mostly by the Tortonian, occupies large areas in Poland. Its stratigraphy is based on mollusks. These fossils, however, occur mainly in rocks deposited near the shore; the deposits of the open sea can be subdivided only on the basis of their microfaunas. For that reason, interest in Miocene foraminifera is great in Poland. The first attempt to carry out a correlation on the basis of foraminifera has been made by Z. Kirchner (1956, *Acta Geol. Polonica*, vol. 6, no. 4). He distinguishes thirteen microfossil zones in a series of Tortonian and lower Sarmatian clays. These zones have been named, but the microfaunal associations are given only for some of the zones. Some of the zones also occur in the East Carpathian Foreland, in the U.S.S.R.

Results of a different kind are found in the work of Mrs. E. Łuszczowska (1957, *Pol. Tow. Geol., Rocznik*, vol. 25 (1955), no. 3), who ascertained that the foraminiferal faunas found in several places are similar, but the rocks which contain these similar associations are attributed by various authors to different stratigraphic zones. The author gives lists of foraminifera of which she has determined altogether about 300 species. In a single bed at Benczyn, near Wadowice, she found 244 species, after examining 200 kg. of material.

In Zgłobice, near Tarnów, on the border of the Carpathians, Tortonian rocks are exposed which are attributed to two series, the older Chodenice beds and the younger Grabowiec beds. In a paper by H. Kozikowski and K. Morawska (1957, *Acta Geol. Polonica*, vol. 7, no. 1), the junior author gives lists of the foraminifera of these series. The microfauna of the Chodenice series is poorer (thirty-seven species were found), whereas the microfauna of the Grabowiec series contains ninety-one species. Similar results had been published in 1955 by Mrs. E. Łuszczowska.

Lists of Miocene foraminifera are also given by S. Alexandrowicz. In one paper (1957, *Inst. Geol.*,

*Bull.*, no. 115), he gives lists of species from lower Tortonian clays in the vicinity of Krakow. They are not complete associations, but show only the most common species, fifty-eight in number, mostly calcareous. In another paper, published jointly with W. Parachoniak (1956, *Acta Geol. Polonica*, vol. 6, no. 3), S. Alexandrowicz reports the discovery of foraminiferal faunas of two zones in the vicinity of Pińczów, between the Carpathians and the Holy Cross Mountains. The lower zone is richer, containing about seventy species, and the upper zone is poorer, containing only about forty species.

A paleontological study of foraminifera is found in a paper by Miss T. Śmigielska (1957, *Pol. Tow. Geol., Rocznik*, vol. 25, no. 3). The author has worked on a microfauna found in clays in a brick-kiln in Gliwice Stare, in Upper Silesia. The fauna contains 169 species, of which nine are arenaceous. The author describes forty species and varieties, among which eight species and one variety are new. She compares this foraminiferal association with other associations of the Polish Miocene, and states that the Gliwice Stare association is most similar to that of the Grabowiec beds near Bochnia described by Mrs. E. Łuszczowska in 1955. On the basis of mollusks, the age of the Grabowiec beds has been determined as middle Tortonian. The paper contains three plates of photographs.

Palynology is developing more and more in Poland; besides the chief topic treated by many authors, which is the investigation of Pleistocene pollen, more and more attention is being paid to the occurrence of spores and pollen grains in older geologic periods. Before 1939, Jan Zerndt wrote on megaspores from coal beds of the Upper Carboniferous in Upper Silesia. At the present time, papers are being published on microspores of the Upper Carboniferous. One of the investigators of microspores is A. Jachowicz, who has been working for several years on that subject. He presents (1957, *Inst. Geol., Bull.*, no. 115) the

results of his investigations in an attempt to fix the boundary between the Westphalian A and the Westphalian B. This boundary lies between the seventeenth and the eighteenth coal seam. He presents tables of characteristic microspores, many species of which were described jointly by S. Dybová and A. Jachowicz. The senior author Mrs. Sonia Dybová, is a micro-paleontologist working in Czechoslovakia.

S. Dybová and A. Jachowicz have also presented brief reports on the subject of their microspore investigations. In one article (1956, *Przegląd Geologiczny*, no. 5), there is a tabulated comparison of the stratigraphic occurrences of forty-three genera of microspores, several of which are new to science. Subsequently, the authors enumerate twenty-one species that are particularly important in stratigraphy. The entire number of established species is 135. Drawings of twenty-five species are given, nine of which are new. In another article (1956, *Przegląd Geologiczny*, no. 11), the same authors discuss the aims and significance of palynologic investigations in the Upper Silesian coal basin, and include stratigraphic definitions on the basis of micro-paleontology.

The above-mentioned authors have also recently published the results of their research on the application of microspores in Upper Carboniferous stratigraphy (1957, *Kwartalnik Geologiczny*, Warsaw, vol. 1, no. 1). This journal is a new Polish periodical devoted to geology. The presence of more than 150 species of microspores and pollen in coal seams and barren rocks of the Upper Silesian productive Carboniferous has been established to date. The authors have distinguished fifteen microspore zones in the sequence extending from the lower beds of the Namurian A to the Westphalian D. The paleontological descriptions of microspores will appear in a joint work by these authors which is now in press in both Poland and Czechoslovakia.



A table compiled by T. Bocheński (1955, *Przegląd Geologiczny*, no. 10) presents information on the stratigraphic distribution of megaspores in Namurian and Westphalian coal beds in Upper Silesia. This table was compiled partly on the basis of older studies by J. Zerndt; after his death, in 1945, investigations of the megaspores of the Upper Carboniferous were resumed, and the results are incorporated in this table. The table lists thirty-seven species of megaspores. It also gives the Polish stratigraphic names for the Upper Carboniferous rocks of Upper Silesia.

A very well preserved flora occurs in the clays of Grojec, in the vicinity of Krakow. The age of the flora is Lower Jurassic. In these clays of Grojec, Miss J. Osztast (1957, *Bull. Acad. Polonaise Sci., Cl. 2*, vol. 5, no. 3, *Sér. Sci. Biol.*) has found angiospermous sporomorphs, which are determined as *Tricolpites* (*Eucommiidites*) *troedsonii* Erdtman.

A short note by Miss M. Pautsch (1957, *Przegląd Geologiczny*, no. 1) presents the results obtained by an investigation of the pollen of the Carpathian Oligocene flysch of the Krosno beds in Poraz, and from marine sediments of Miocene age from Świniary, near Solec. Pollen forms are designated only as genera; there are also some pollen forms that are not determined taxonomically, but are named only on the basis of their external morphology. This work is an application of pollen analysis in the correlation of monotonous marine sediments. It is worth mentioning that a paper by this author on Keuper pollen in Poland will appear soon in *MICROPALAEONTOLOGY*.

The pollen of the brown coals of Poland is treated in three papers by Miss J. Doktorowicz-Hrebnička. In one paper (1957, *Inst. Geol., Prace*, Warsaw, vol. 15), the author has published the results of her research on material from two bore-holes in the area of Babina, near Mużakow, Żary district, in Lower Silesia. On the basis of microfloristic investigations, the age of the six seams of brown coal is:

Seam I ..... Interglacial(?)  
Seam II ..... Lower Miocene  
Seams III, IV, V . Chattian-Aquitanian  
Seam VI ..... Oligocene

The author has found that the "upper seam" of brown coal, so called by G. V. Raatz (1937), is probably the oldest seam secondarily displaced by the movements of glaciers.

In a second paper, J. Doktorowicz-Hrebnička (1957, *op. cit.*) presents the results of pollen analysis of brown coal from three superposed seams in the area of Mirosławice Górne, Żary district, in Lower Silesia. The seams of brown coal are considerably disturbed by glacio-tectonic movements, but the author has found that the lower seam appears to be the oldest and the upper the youngest. The age of the formation is Lower Miocene.

In a third paper, the author deals with the pollen spectra of brown coal from the Poznań clays, which are regarded as Pliocene. The material was collected from two localities, one in the area of Olsztyn (northern Poland), the other situated 40 km. northwest of Warsaw. Pollen analysis shows in both cases that this was a period when enormous *carex* bogs, with numerous species of herbaceous plants as well as of alder, existed. The age of the brown coal is probably Lower or Middle Pliocene.

We will here mention briefly the investigations of Quaternary pollen. Several authors published their findings during 1956 in *Bulletin no. 100* of the *Instytut Geologiczny*. Miss J. Dyakowska mentions pollen from the Mindel-Riss interglacial stage (Masovian I, in Polish nomenclature) from the profile of Wylezin, near Garwolin (central Poland), and Miss M. Sobolewska mentions pollen of the same stage from Syrniki and Olszewice on the Wieprz River in Lublin Voivodcy. The following authors mention pollen from the Riss-Würm interglacial stage (Masovian II, according to the Polish nomenclature established by Professor W. Szafer): K. Bittner

from Otapy and Czarna Wieś near Białystok, Nowe Miasto near Bydgoszcz, and Kłękówek near Łódź; A. Środoń from Szela near Poznań; and A. Środoń and M. Gołbowa from Bedlno, near Końskie (central Poland). Another paper by J. Dyakowska deals with the results of the pollen analysis of ice-dammed clays, and considers the problem of the significance of reworked pollen in the pollen diagrams.

A paper on *Coccolithophoridae* has been published for the first time in Poland, by Miss H. Górka (1957, *Acta Paleontologica Polonica*, Warsaw, vol. 2, no. 2-3). The author describes her methods of study, and gives descriptions of sixty-six species, among which sixty are new. Out of a total of eleven genera, two are new.

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#### UNITED STATES - EAST COAST



RAYMOND C. DOUGLASS

Smithsonian Institution (U. S. National Museum), Washington, D. C.

Dr. Alfred R. Loeblich, Jr., has resigned from the National Museum staff to join the California Research Corporation in California. He has not been replaced here.

Several micropaleontologists consulted the collections during 1957. Among them are Esteban Boltovskoy, from Buenos Aires; Patsy B. Smith, from the Fuels Branch of the U. S. Geological Survey, Claremont, California; Priscilla J. Militante, from the University of the Philip-

pinus; A. F. M. Hohenal Hague, of the Geological Survey of Pakistan; and Raymond L. Artusy, of New York University.

Richard S. Boardman recently transferred from the U. S. Geological Survey to the U. S. National Museum, where he is continuing to work on fossil Bryozoa. A paper entitled "Trepomatous Bryozoa of the Hamilton group of New York State" was completed last spring. Present research includes a study of rhomboporoid Bryozoa from the Hamilton group of New York, and the initial phase of a restudy of the type species of Lower Paleozoic trepomatous Bryozoa.

**U. S. Geological Survey  
Washington, D. C.**

Ruth Todd reports that she is currently making an ecologic study of foraminifera from Recent sediments of Onotoa in the Gilbert Islands. With Doris Low, she is studying Recent foraminifera collected from shallow water around Martha's Vineyard, and with Paul Blackmon, she is studying the results of X-ray analyses to determine the mineralogical nature of the tests of foraminifera (whether they are calcite or aragonite) and the significance of magnesium content in calcite tests.

A paper on the foraminifera from eighteen deep-sea cores from the western Mediterranean, collected by the Swedish ship *Albatross*, is in press. Also in press is a description of a small Tertiary fauna from the Arctic coast of Alaska. A report on the fossil foraminifera from two deep holes drilled on Eniwetok Atoll has been completed in collaboration with Doris Low. Miss Todd's publications during the past year include one with Paul Bronnimann on Recent foraminifera from the Gulf of Paria, Trinidad, and one on the Tertiary and Recent smaller foraminifera of Saipan.

Lloyd Henbest is studying the ecology and life association of algae and foraminifera in a Pennsylvanian limestone from Oklahoma. Raymond C. Douglass has completed a

study of *Orbitolina* in North America, and the report is awaiting publication as a Professional Paper of the U. S. Geological Survey. He is extending the study of *Orbitolina* to include its occurrences in Central and South America and in several Caribbean islands. In addition to these studies, Douglass is returning to the study of the fusuline foraminifera of the western United States. As the new correspondent for the United States East Coast, Douglass would appreciate hearing from any micropaleontologists who may have been missed in his canvass for information. He acknowledges with thanks the excellent response received.

I. G. Sohn reports that he has completed a revision (after technical review) of the first part of his studies on "The Paleozoic species of *Bairdia* and related genera." He is assembling plates for the second part of his "Revision of Upper Paleozoic ostracode genera: *Acratia* to *Balanoides*." He is now processing samples of Middle Mesozoic sediments collected recently in the Black Hills of South Dakota, and he is presenting a report of progress at the annual meeting of the Geological Society of America, held at Atlantic City in November, 1957.

Wilbur H. Hass is continuing his study of the ranges of disjunct conodont genera and species in the North American standard Upper Devonian succession, in the New York area, and in the standard Mississippian succession, in the middle Mississippi Valley area. He has completed a paper on "Conodonts of the Chappel limestone, Texas." He has also completed a joint paper with Preston E. Cloud, Jr., and Virgil E. Barnes, entitled "Devonian-Mississippian transition in central Texas."

**McLean Paleontological Laboratory  
Alexandria, Virginia**

Work at the McLean Laboratory has been extended to include Ostracoda and holothurians. Research activities here have resulted in publication of "The Ostracoda of the

Yorktown formation in the York-James Peninsula of Virginia" (1957, Bull. Amer. Pal., vol. 38, no. 167). Dr. Esteban Boltovskoy of Argentina and Mr. S. N. Singh of India were visitors at the laboratory during 1957.

**Columbia University  
Lamont Geological Observatory  
Palisades, New York**

W. H. Allan is studying the ecology of planktonic foraminifera from plankton tows in the western North Atlantic and the Caribbean Sea in an attempt to determine their horizontal, vertical and seasonal distributions and standing crops. Their correlation with temperature, salinity, light, and nutrient conditions in the ocean should provide additional information with which Cenozoic paleoecology can be interpreted. It has been found that planktonic foraminifera are most abundant in numbers and varied in species in the Gulf Stream system, in contrast to the Central Atlantic water mass (Sargasso Sea) and slope waters. Pronounced seasonal variations in distribution were observed in Bermuda waters, where, in the late fall and winter, temperate species replace subtropical species, with the reverse occurring in the late spring and summer.

A large suite of long sediment-cores from the South Atlantic was brought home recently by the R/V *Vema* of the Lamont Geological Observatory. These cores are presently being opened and sampled for foraminifera by D. B. Ericson. An attempt will be made to trace the now well-established faunal zones of the North Atlantic southward into the South Atlantic. The objective is to gain further evidence of contemporaneity of glacial ages in the Northern and Southern Hemispheres.

**Cornell University, Ithaca, New York**

Professor W. Storrs Cole reports that he is continuing work on the Pacific Islands for the U. S. Geological Survey. K. N. Sachs, Jr., is studying American species of the genus *Lepidocyclus*. Philip Hewitt is

studying larger foraminifera from the type localities of certain selected Cuban Tertiary formations.

Since January 1, 1957, Professor Cole has published three papers. The first is entitled "Late Oligocene larger foraminifera from Barro Colorado Island, Panama Canal Zone" (Bull. Amer. Pal., vol. 37, no. 163, pp. 313-338, pls. 24-30). Another paper is on "Variation in American species of *Lepidocyclina*" (ibid., vol. 38, no. 166, pp. 31-51, pls. 1-6), and the third, "Larger foraminifera [of Saipan Island]," forms a part of U. S. Geol. Survey Professional Paper no. 280. K. N. Sachs, Jr., has published a paper on a "Restudy of some Cuban larger foraminifera" (Cushman Found. Foram. Res., Contr., vol. 8, pt. 3, pp. 106-120, pls. 14-17). Professor Cole also has a paper in press, on "Larger foraminifera from Eniwetok Atoll drill holes," which will form a part of U. S. Geol. Survey Professional Paper no. 260. He has also completed a manuscript on the larger foraminifera of the island of Guam, which is to be published as a part of a Professional Paper on that island, but which is not yet in press.

**Yale University  
Peabody Museum of Natural History  
New Haven, Connecticut**

Professor Karl M. Waagé reports that the paleontological laboratory at Peabody has two projects under way in the field of micropaleontology. Both are dissertation problems of resident graduate students. Don L. Eicher is completing a study of the microfossils in the marine Lower Cretaceous rocks of Wyoming. Charles Ross has recently begun a study of the stratigraphy of the Permian Wolfcamp formation in its type area; he intends to make use of both the fusulines and the smaller foraminifera.

Dr. Carl O. Dunbar has a report essentially completed for publication, dealing with the fusulines of the Shibar Pass region in Afghanistan. He is also beginning a study of fusulines from the Permian of Northeast Greenland, and has in progress a study of fusulines from western Canada.

**Harvard University  
Museum of Comparative Zoology  
Cambridge, Massachusetts**

Professor Harry B. Whittington reports that Richard Cifelli is continuing his work on Middle Jurassic foraminifera from Great Britain. Mr. Cifelli is a graduate student who is now teaching at Brown University, Providence, Rhode Island.

**Woods Hole Oceanographic Institution  
Woods Hole, Massachusetts**

Dr. William D. Athearn reports that he and his assistant, Barbara Gill, have just completed cataloguing ecological information on Recent foraminifera of the Gulf of Mexico and the Caribbean Sea for Esso Research and Engineering Company. The information, which is based solely on the literature, is to remain their property for at least a year. For the past year, Dr. Athearn has been making bimonthly collections of foraminifera from several marsh stations on Cape Cod, along with salinity and temperature measurements. These collections and data have been forwarded to Dr. Frances L. Parker, at the Scripps Institution of Oceanography, La Jolla, California, who is working them up.

During November and December, 1957, Dr. Athearn expects to take part in a cruise to the Cariaco Trench, off northern Venezuela, for general submarine geological studies. In view of the anaerobic bottom conditions in the trench, he does not expect to find many foraminifera, but he hopes to make a few incidental collections in the Caribbean area during the cruise.

**New York University**

A number of research projects have been under way in the Department of Geology at New York University during the past year. Harold L. Cousminer is continuing his study of polymorphism in several living and fossil foraminiferal populations. Gilbert J. Brenner is making a zoogeographic zonation of the Gulf of California. He hopes to trace the northern limits of the Panamic (tropical) foraminiferal fauna. Josephine Sperazza is completing a

biostratigraphic study of the Cretaceous and Tertiary foraminifera of Sicily. Richard Charnatz is continuing his work as Special Assistant to Dr. Henry I. Hirshfield in the compilation of a reference collection of foraminifera from Eniwetok Atoll for the Atomic Energy Commission and the University of Hawaii.

Darwin O. Hemer is working on the correlation of the Rub' al Khali section with that at Dammam, in Saudi Arabia. Peter Tuozzolo has completed a study of Holocene foraminiferal distribution in New York Harbor and vicinity. Robert J. Popper has completed a study of the "microforaminifera" of the early Tertiary of the Gulf Coast. Harry Leffingwell has just finished a study of the microfossils of the Vicksburg of Texas. Delbert Potter is now completing his research on the spores and pollen of the Dakota formation of Oklahoma. Emanuel J. Nieves has concluded his study of the foraminifera and type sediments of Lower New York Bay. Jerome A. Brock is continuing work on the shallow- and brackish-water foraminifera of Tampa Bay, Florida. Feodor Bourgeois is working on plant microfossils from Arabia. David D. Hughes is continuing his study of the foraminifera of the Cyrenaican Coast, northern Libya.

Dr. Leonard R. Wilson left New York University in the spring of 1957, to accept positions with the University of Oklahoma and the Geological Survey of that state. Raymond L. Artusy was appointed to the faculty of New York University in the fall of 1957, to take over Dr. Wilson's work in sedimentation and stratigraphy and to teach a course in Ostracoda.

**American Museum of Natural History  
New York**

The principal research activity in the Department of Micropaleontology at the American Museum of Natural History during the past year has been a study of "microforaminifera," which is being made by Hans J. Behm and Robert J. Popper under a Carter Oil Company grant.



Angelina R. Messina collected living foraminifera from Bimini for a portion of this study. A companion study on the hystrichospherids was made by Eugene J. Tynan under a Carter Oil Company grant. The latter study was carried out under the direction of Professor Leonard R. Wilson.

Hans J. Behm is continuing his research on the ecology of Recent brackish-water foraminifera of Staten Island, Long Island and New Jersey. Work on the sediments and micro-organisms of Long Island Sound has continued during the past year. Early last spring, a 100-foot research vessel was obtained from the Corps of Engineers, U. S. Army, and is being used as a floating laboratory in this work. Contract work for the Arabian American Oil Company continued throughout the year, and a number of research projects were undertaken for various other oil companies.

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## VENEZUELA



BOGUSLAW J. SZENK

Creole Petroleum Corporation

The following paleontologists are presently employed at Creole's Maracaibo laboratory: Charles E. Key (head), Jesse J. Howard, Lee B.

Gibson, George Fraunfelner (macro-paleontology), and Peter Ronai. Harry W. Anisgard has left Maracaibo to work for the Carter Oil Company at Billings, Montana. Jay G. Marks has also left Maracaibo, and has accepted a position with the Carter Oil Company at Denver, Colorado. The laboratory staff at Jusepín (Monagas) consists of the following micropaleontologists: Gordon M. Sowers (head), Dr. Pedro J. Bermudez, Arthur N. Dusenbury, and John Sulek. Dr. Bermudez has continued his study of the genera of the Globigerinidae and Globorotaliidae in the Antillean region, having assembled, to date, 185 species from the Paleocene to the Recent. Mr. Dusenbury is awaiting the publication of a paper, written in collaboration with L. E. Becker, on Oligocene foraminifera from Colombia, which is to be published as a Special Publication of the Cushman Foundation for Foraminiferal Research. The coordination of the micropaleontological work of Creole's laboratories is in the hands of Dr. Virgil Winkler.

## Compañía Shell de Venezuela

R. W. Pooley was transferred from Maracaibo to Caracas at the end of October, 1956, to take charge of Shell's laboratory in Caracas. J. E. Dollé left Caracas for an assignment in another area at the beginning of February, 1957. A. Ford joined Shell's Maracaibo laboratory staff at the beginning of 1957.

## Mene Grande Oil Company

Leslie Ray Moore will soon join the staff of Mene Grande's stratigraphic laboratory in Caracas. Mr. Moore obtained his M.A. degree in micropaleontology in June, 1957, from the University of Oklahoma, at Norman, Oklahoma. Prior to his new activities Mr. Moore was employed for four years in various capacities by the Fort Worth Division of the Gulf

Oil Corporation. Before joining Gulf he was assistant to Dr. R. W. Harris at the University of Oklahoma and also worked for the U. S. Geological Survey.

## Texas Petroleum Company

Dr. C. M. B. Caudri, head of the Caracas laboratory, is presently working on a study of the larger foraminifera of Trinidad. This study will form part of Dr. Kugler's forthcoming paper on the geology of Trinidad.

## Consultants

Frank Amato, who was formerly a stratigrapher and micropaleontologist with the Standard of California Group in Venezuela, Colombia, and Peru, and for the past eight months with Martin-Sykes and Associates in Caracas, has recently become an independent consultant in geology and micropaleontology, with a laboratory in Caracas. Studies will be particularly applicable to Venezuela, Colombia, Peru and Ecuador. Mr. Amato is prepared to process surface and well samples and to perform regional and local stratigraphic studies based on lithology and fauna. Instead of the customary rollers or gasoline breakdown methods of preparation, Mr. Amato uses osterizers to prepare a sample for washing. He finds that this procedure results in more rapid washing, and with hard siliceous shales, the rapidly rotating blades strike the shale and cleanly "pop" the foraminifera out, much as an ammonite is popped out from a concretion with a hard blow of the hammer. The rotating blades apparently do not noticeably produce disintegration of the foraminifera, even with very fragile types, such as those of the Chira shale of Peru. Mr. Amato's mailing address is Apartado del Este 4991, Caracas, Venezuela.

BOGUSLAW J. SZENK

Mene Grande Oil Company  
Caracas



